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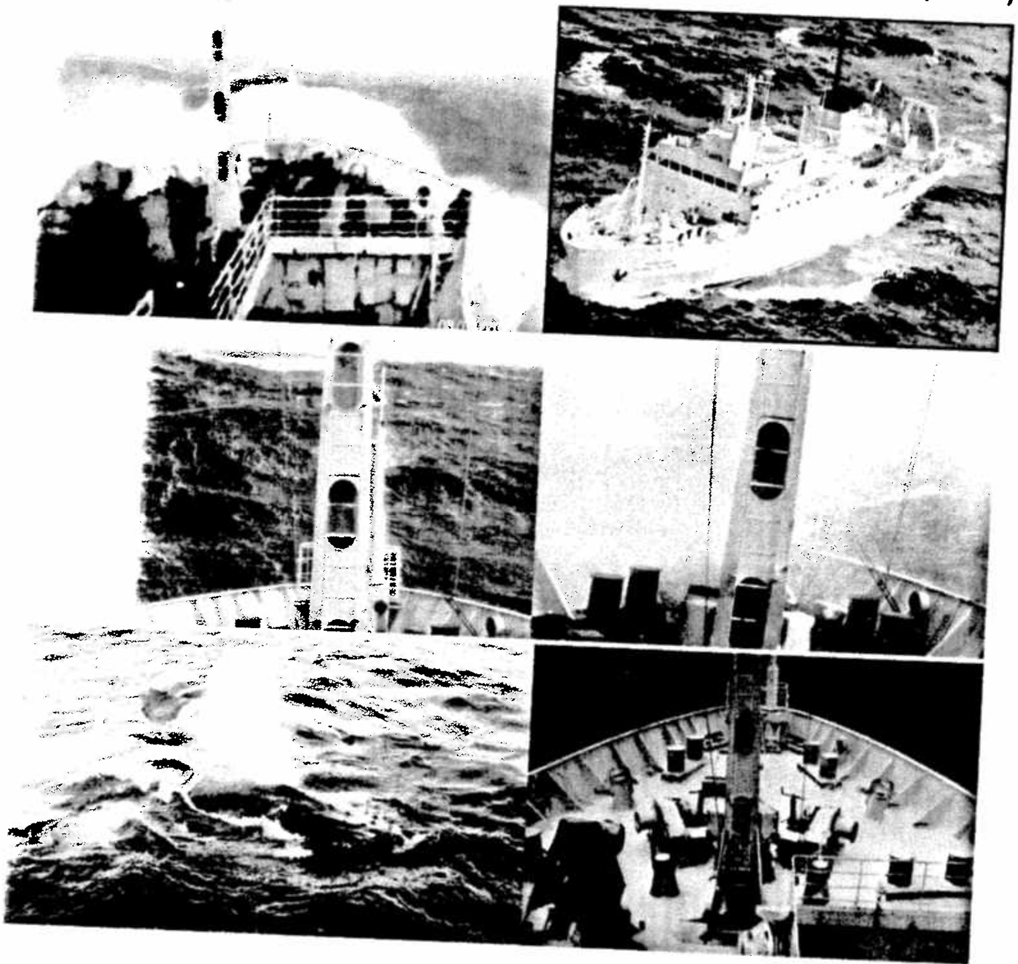
SOUTHERN OCEAN EXPEDITION-2009 REPORT

I/B AKADEMIK BORIS PETROV

CRUISE – 035/36

(February 10th, 2009 to April 14th, 2009)



National Centre for Antarctic & Ocean Research,

(Ministry of Earth Sciences),

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1. Preview

For participating in the 3rd expedition to Southern Ocean (**SO**) scientists from different organizations left India (Goa) on 10th February 2009 and boarded vessel I/B AKADEMIK BORIS PETROV at Port Louis, Mauritius on 11th February 2009. The SO Expedition - 2009 was launched on 12th February 2009 at 2100 hrs IST (2030 hrs local time) from Port Louis, Mauritius for a 64 days cruise in high seas. The expedition was planned to collect multidisciplinary environmental data in the Indian sector of SO up to the shelf of Antarctic continent. A team of 24 scientists from National Centre for Antarctic & Ocean Research (NCAOR), Physical Research Laboratory (PRL), Centre for Marine Living Resources & Ecology (CMLRE), Indian Meteorological Department (IMD), K Banerjee Centre of Atmospheric & Ocean Studies (KBCAOS), Goa and Karnataka Universities and two engineers & two shipboard assistants from NCAOR participated in this cruise.

Acquisition of data from underway instruments and collection of multidisciplinary data using the onboard equipments began after crossing the Exclusive Economic Zone (EEZ) of Mauritius (from 25°S onwards). Observations were carried out in the study area of SO upto 66°10'S. Period spent in cold water (South of 40° south) from 19th February 2009 at 1935 hrs to 20th March 2009 at 1850 hrs. Vessel arrived at Mauritius on 26th March 2009 after completion of observations in the SO region. There was a port call at Port Louis, Mauritius for four days in connection with logistic requirements. The vessel started its return journey from Port Louis, Mauritius on 29th March 2009 and arrived at Mormugao port (Goa) on 14th April 2009.

Atmospheric parameters (Air sample, Wind speed, Wind direction, Air temperature, Humidity, Barometric Pressure, Net radiometer); Physical parameters (Sea surface temperature, Sea surface salinity using autosal, Temperature - Salinity using CTD etc); Chemical parameters (Dissolved oxygen, pH, Nutrients, etc); Biological parameters (Phytoplankton, Chlorophyll, Zooplanktons & Benthos, Biochemical parameters, Biological species etc); Geological parameter (Gravity cores and Grab samples) and Geophysical parameters (Bathymetry, survey by Multi-beam sonar, and Parasound sub bottom profiling) were collected along meridional sections 57°30'E and 48°E; along zonal section 65°30'S; and along the return track from Mauritius to India (Goa). Astronomical visual moving objects were identified in clear sky with naked eyes.

Aerosol Optical Depth (AOD) was measured at half hourly interval using Microtop II sun-photometer during clear cloud free days throughout the cruise track. Meteorological parameters were measured using handheld equipments at 3 hourly intervals in conjunction with continuous AWS measurement (at one minute interval). CO_2 samples were collected from 17 stations along 57°30'E. Air samples were collected from 97 stations. Surface sea water samples were collected from 107 stations at one degree interval after crossing EEZ of Mauritius i.e. southward from 25°S to study biogeochemical parameters. XBTs were launched at one-degree interval from 28°S to 35°S (10 numbers). XCTDs were launched at 20 nautical mile interval from 35°30'S in the frontal region (45 numbers). Temperature – salinity (CTD) data was collected using Mark IIIB CTD, 29 stations along 57°30'E meridional section; 8 stations along 65°30'S zonal sections; 24 stations along 48°E meridional section; and 22 stations along Mauritius to India (Goa) cruise track. At two degree interval rosette sampler was operated from 32°S onwards, however it was operated at one degree interval in tropics from Mauritius to India (Goa). Sea water samples were collected at different depths from ~56 stations along meridional sections 57°30'E and 48°E and in the return track from Mauritius to India (Goa) for analyzing various parameters such as dissolved oxygen, pH, and nutrients (Nitrate, Nitrite, Phosphate and Silicate) etc. Further, sea water samples were collected for analyzing phytoplankton, chlorophyll and biogeochemical parameters.

Multiple Plankton Net (MPN) of mesh size 10 μm and 100 μm was operated (6 stations) to collect phytoplankton samples in the upper 200 m water column. Bongo net of mesh size 200 μm was dragged for 10 minutes with 2 knot ship speed at two degree interval to collect zooplankton samples in the surface water at 39 stations. Gravity corer was operated in the SO region however no sediment was collected could be due to bottom topography. Coastal sediment samples were collected in the Antarctic continental shelf in the zonal track using a Van veen grab. Benthic samples were collected at 3 stations to study the benthic biology. Total 5 numbers of sediment (Grab) samples were collected. Hydrosweep swath underway bathymetry data and Parasound sub bottom profiler data were collected along ship track. Due to technical problems in Atlas Hydrosweep system, swath bathymetric data could not be collected in the return. Scientific observations and underway data acquisition stopped before entering EEZ of India.

It is expected that this multi-disciplinary oceanographic data collected in the SO sector as well as in tropics will help to bring out new insights in our scientific understanding. Considering the requirement of the expedition member's data collection during SO Expedition - 2009 is satisfactory although there were some instrumental errors occurred due to rough weather conditions at high seas. Even in the bed weather/rough sea conditions tremendous efforts were made by the expedition members for data collection which will help us for more scientific understanding of the unknown areas of Southern Ocean.

2. Introduction

The vessel sailed off from Port Louis, Mauritius harbor on 12th February 2009 around 2100 hrs and after crossing Exclusive Economic Zone (EEZ) of Mauritius underway-geophysical data collection has been started immediately. From Mauritius, the vessel has sailed towards south and it has reached the starting location with coordinates 32°S and 57°30'E by 16th February 2009 at 1030 hrs. (**Fig. 1**) from which meridional section was sampled upto southernmost point 66°09.59'S.

Southern Ocean (SO) is a region where Antarctic Circumpolar Current (ACC) encircles the Antarctic continent 360 days of the year. The SO plays a prominent role in controlling the global ocean–atmospheric climate system and thereby having an impact on the climate of the earth. The various water masses of the world ocean originate in this region. Under the changing atmospheric conditions, the vertical and horizontal structures of Antarctic Surface Water (AASW) of the Indian sector of the SO, as a whole, have not been studied to a greater extent, although some detailed studies exist for limited locations. These water masses play an important role in the global climate system as reservoirs of heat, freshwater and dissolved gases and act as a damping mechanism on variations in the global climate. Some studies have shown that due to global warming, parts of Antarctic ice sheet are melting and the SO is getting more and more melt water. The SO is also characterized by high availability of macronutrients (phosphate, nitrate and silicate) which should sustain high primary productivity in that area. In spite of high macronutrient concentrations, chlorophyll and primary productivity are typical of oligotrophic to mesotrophic conditions in large areas of the SO. This region is very important reservoir which highly affects our monsoon system. SO is still not very much explored therefore various aspects has been taken up to explore the SO. It is in this context that the National Centre for Antarctic and Ocean Research (NCAOR), Goa initiated a multi-parameter oceanographic study in the SO sector of the India Ocean.

3. Objectives

The main objective of this cruise was to explore the Southern Ocean (SO) in its multi-disciplinary oceanographic, and atmospheric fields. A team of scientists from NCAOR, NIO, PRL, CMLRA, IMD, KBCAOS (Allahabad University), Goa University, Karnataka University, apart from the ship maintenance staff from NCAOR took part in the expedition. The data collection was so planned as to reoccupy some of the areas where earlier data were available and also to collect new data in some unexplored areas, which was not attempted earlier. The objectives of the expedition discipline wise, are as follows:

a. Atmospheric Sciences

1. To study land ocean transport of aerosol.
2. To examine the characteristics of the aerosol particles found over the SO and to estimate their radiative forcing.
3. To compute air sea fluxes using bulk algorithm.
4. To collect meteorological parameters in 3 hourly interval for daily weather report.
5. To study stable isotopic of atmospheric water vapor to understand ocean-atmosphere exchange and cloud formation process. Also to understand mixing of the vapor with free air.
6. To characterize fractionation factor between water-vapor and water-ice during isotopic fractionation for different surface and atmospheric conditions.
7. To understand extent and strength of evaporation/precipitation and melting/freezing processes over surface waters.
8. To trace extent of freezing zone and understand changes in last 3 years due to warming.

9. Construct high resolution stable isotopic distribution for surface water, deep waters and atmospheric water vapor.
10. To estimate the rate of increase of concentration of major green house gases (CO_2, CH_4 and N_2O) in recent times.
11. To estimate the air-sea CO_2 flux from various parts of the SO.
12. To establish the existing belief that the Antarctic and sub Antarctic regions are strong sinks of CO_2.

b. Physical Oceanography & Simulation Studies

1. Inter-annual variability of geostrophic circulation & transport.
2. Studies on current structure and upper Ocean heat budget.
3. Modulation of thermohaline structure and water masses.
4. To study sensitivity of Ocean General Circulation Model (OGCM) with respect to real time forcing and boundary condition.
5. To compare seasonal and inter-annual variation of fluxes and long-term variability of surface heat transport with model results
6. Comparison of the model results in the study region of the Tropical Indian Ocean.
7. To compare estimated fluxes with available reanalysis climatology.

c. Marine Chemistry

1. To study the spatial variation of different chemical parameters (like Total inorganic and organic carbon, dissolved Oxygen, nutrients, trace metals and p^H) in the SO.
2. To estimate whether the SO is a source or sink for atmospheric carbon dioxide.
3. Characterization of the trace element and isotope distributions and gradients across the circum-Antarctic fronts at different latitudes.

4. To track the inflow and outflow of water in the SO to characterize marine input, loss and mixing of trace elements and isotopes.

d. Marine Biology

1. To study spatial distribution of chlorophyll and phytoplankton in SO.
2. To study the vertical distribution, abundance, viability and culturability of bacteria in SO.
3. To study the spatial distribution of Coccolithophores in SO.
4. To study spatial variation of diatoms in surface sediments of Continental shelf area of SO.
5. To study the biocoenosis and thanatocoenosis of diatoms in SO.
6. To carry out time series observations for study of phytoplankton in coastal areas of SO.
7. To understand the composition and morphology of the filtered water samples (difft. depth) by using AFM, Raman Spectroscopy, SEM, HRTEM.
8. Silica shell depending upon above characterization will be identified for their potential application in optical sensors and nanoparticle based drug delivery.
9. Silica shell will be coated with different nanophosphor to enhance the optical properties.
10. To Estimate primary productivity in the SO using ^{13}C tracer technique.
11. To quantify the carbon sequestration through biological activity in the SO using ^{13}C-^{15}N coupled tracer technique.
12. To estimate the new and regenerated production in the region using ^{15}N tracer.
13. Understand the carbon and nitrogen isotopic compositions ($\delta^{13}C$ and $\delta^{15}N$) of natural surface plankton in the region.

14. Compare the results obtained from this study with the available climatology data in other parts of the world's oceans.
15. To document the gelatinous zooplankton diversity and abundance in the SO.
16. To establish a database of the plankton collected, both at the species and molecular level.

e. Geology

1. To study the variation of the suspended particular matter with respect to latitude and depth of the water sample at specified location.
2. Geochemical analysis (metal bound to suspended matter) of specified location.
3. To understand changing climatic condition and its effect on SO.
4. To study the spatial variation of living as well as fossilized foraminifera in Continental shelf area of SO.
5. To investigate the geochemical and sedimentological parameters in sediment samples of SO.
6. To study the sediments in the SO as well as Antarctica shelf to characterize the sedimentary processes involved and the provenance of the sediments.

f. Geophysics

1. Bathymetric survey along the cruise track.
2. Characteristics of sediments based on Parasond along cruise track.

g. Astronomy

1. To record the occurrence of unidentified moving and illuminating objects in the night sky.

4. Participants

There were 26 participants in total (**Plate** 1), 12 from NCAOR out of which two are non scientific, 5 from PRL, 3 from CMLRE, 2 from IMD, 1 each from KBCAOS (Allahabad University), Goa University, Karnataka University, and Gujarat University. The list of the participants is as follows:

4.1 Scientific Component:

National Centre for Antarctic & Ocean Research (NCAOR), Goa

1. Dr. S. M. Pednekar,	*Scientist*, **Chief of Expedition**
2. Dr. M.V. Ramesh,	*Research Associate*
3. Dr. Sunil Kumar Shukla,	*Research Associate*
4. Ms. Racheal Chacko,	*Research Scientist*
5. Mr. Shramik M. Patil,	*Research Fellow*
6. Mr. Suhas S. Shetye,	*Research Fellow*
7. Ms. Sharon B. Noronha,	*Research Fellow*
8. Mr. Jenson V. George,	*Research Fellow*
9. Mr. Jeyaraj Vishwanathan,	*Mechanical Engineer*
10. Mr. N. Dhanasekaran,	*Electronic Engineer*

Physical Research Laboratory (PRL), Ahmeadabad

11. Mr. Rohit Srivastava,	*Senior Res. Fellow*, **Dy. Chief Scientist**
12. Mr. Naveen Gandhi,	*Research Fellow*
13. Mr. Amzad H. Lashkar,	*Research Fellow*
14. Mr. Vineet Goswami,	*Research Fellow*
15. Ms. Jayati Chatterjee,	*Research Fellow*

Centre for Marine Living Resources & Ecology (CMLRE), Kochi

16. Dr. P. J. Antony, *Research Fellow*
17. Ms. Bhuvaneshwari, *Research Fellow*
18. Ms. Elizabeth John, *Research Fellow*

Indian Meteorological Department (IMD), New Delhi

19. Mr. H. R. Mahajan, *Scientific Assistant*
20. Mr. Sumant Kumar Saha, *Senior Observer*

KBanerjee Center of Atmospheric & Ocean Studies (KBCAOS), (Allahabad University), **Allahabad**

21. Mr. Prashant Kumar Singh, *Research Fellow*

Goa University (GU), Goa

22. Ms. Ratna Prabha, *Research Fellow*

Karnataka University (KU), Dharwad

23. Dr. Annie Kurian, *Research Associate*

Gujarat University (GU), Ahmeadbad

24. Mr. Rahul Shah *Student*

4.2 Non Scientific Component:

National Centre for Antarctic & Ocean Research (NCAOR), Goa

25. Mr. N. Tandel, *Shipboard Assistant*
26. Mr. Deepeshkumar, *Shipboard Assistant*

4.3 Ship's Scientific Component:

1.	Mr. Petruchik Nikolay	*Chief of expedition*
2.	Mr. Sukhoruk Vladimir	*Chief Scientist*
3.	Mr. Morits Igor	*Ch Engineer Scientist*
4.	Mr. Prusakov Boris	*Ch. Detachment*
5.	Mr. Borisov Alexander	*Ch Detachment*

4.4 Ship's Non Scientific Component:

6.	Capt. Vtorov Igor	*Captain & Master*
7.	Mr. Kurganskiy Oleg	*Chief mate*
8.	Mr. Kashikov Vyacheslav	*2nd mate*
9.	Mr. Kalsin Mikhail	*Chief Engineer*
10.	Mr. Ganoshenko Anatoliy	*Chief Electrical Engineer*
11.	Mr. Krytin Viktor	*Chief Radio Officer*
12.	Dr. Kkopylov Nikolay	*Medical Officer*

5. Cruise Itinerary

- Departure at Port Louis, Mauritius : **February 12th, 2009**
- Arrival at Port Louis, Mauritius : **March 26th, 2009 (Return)**
- Stay at Port Louis, Mauritius : **March 26th to March 29th, 2009**
- Departure at Port Louis, Mauritius : **March 29th, 2009**
- Arrival in India (Goa) : **April 14th, 2009**

6. Equipments Used / Operated

- Microtop-II sun-photometer with five frequency channels (340 nm, 440 nm, 500 nm, 675 nm & 870 nm and build in barometer / altimeter.
- Bucket thermometer for Sea Surface Temperature (SST)
- Wind vane, anemometer, wet bulb, dry bulb temperature and barometer.
- Automatic Weather Station (AWS) (wind sensor, air temperature, humidity sensor, barometric pressure sensor, net radiometer and data logger).
- Expendable Bathythermograph (XBT)
- Expendable CTD (XCTD)
- Carousel Auto Fire Module (AFM) attached with Portable CTD
- CTD (Conductivity Temperature Depth)
- Niskin bottles
- Goflo Niskin bottles
- CTD winch
- Autosal for Sea Surface Salinity (SSS)
- Titration -Dosimat unit
- Columetric meter
- Vaccum pump
- Barnstead diamond water system
- Barnstead diamond storage reservoir
- Milli-Q water purifier
- $_{p}$H meter
- Spectorm analyzer
- Bongo net
- Multi-Plankton Net (MPN)
- Hydrosweep swath (Multibeam Atlas DS-2)
- Parasound sub bottom profiler

- Gravity corer
- Deep-Sea winch
- Van Veen Grab (big & small size)
- Auto clave
- Oven
- Hot plates

7. Parameters Measured

- Aerosol Optical Depth
- Meteorological (wind speed and wind direction, air temperature, wet bulb temperature, barometric pressure, net radiometer, clouds types).
- Automatic Weather Station (AWS) parameters.
- Physical (sea surface temperature, sea surface salinity using Autosal, temperature, salinity depth profiles, oxygen, PAR, chlorophyll profiles etc.).
- Chemical (dissolved oxygen, $_pH$, nutrients, etc.)
- Biological (Phytoplankton, Chlorophyll, Zooplanktons & Benthos, Biochemical parameters)
- Geological (Gravity corer and Grab sampler)
- Geophysical (Bathymetry, Multi-beam swath, and Parasound profiling)
- Astronomical (moving objects in sky)

8. Data Statistics

a. Atmospheric Sciences

Atmospheric data is important as it plays major role in ocean dynamic processes. Participants from NCAOR (objectives 1-3), IMD & KBCAOS (objective 4), PRL (objectives 5-12) are involved in the atmospheric objectives. Aerosol particles data collection using Microtop II sun-photometry had been carried out by NCAOR. Meteorological data was collected at 1 minute interval using AWS (Automatic Weather Station) in the entire cruise track. Synoptic meteorological observations in 3 hourly intervals was carried out by IMD and KBCAOS. Study on stable isotopes of oxygen and hydrogen was done by PRL group.

Introduction: Aerosols are tiny particles of different chemical composition, suspended in air for a duration ranging from a few hours to a few days. Aerosols can impact the earth's weather and climate by altering the earth's radiation budget mainly through scattering and absorbing the solar radiation and to a lesser extent, by absorbing the outgoing terrestrial long-wave radiation. Over the ocean it is mainly the sea salt particles produced by breaking of air bubbles by surface winds and to a lesser extent, sulphate particles produced from dimethyl sulphide emitted by phytoplankton. Further atmospheric parameters play role for weather prediction and ocean dynamical processes. Also atmospheric parameters are useful as input for running general circulation model.

Stable isotopes of oxygen and hydrogen have been used as reliable tracers for evaporation / precipitation, melting of sea ice, glacial, river run-off, deep water masses, and their formation processes. Combined study of stable hydrogen (δD) and oxygen ($\delta^{18}O$) isotopes and salinity can be ideal to monitor various processes involved in the oceans. The vapor acts as a mediator between ocean-atmosphere for energy exchange and cloud formation. The amount of heat transfer depends on the efficiency of the vapor formation. The evaporation processes is dependent on the physical processes over the oceans surface. The Antarctic and sub-Antarctic zones are believed to be a strong sinks of atmospheric CO_2. Recent study showed that the uptake of CO_2 by ocean water is decreasing due to warming. Predictions of future atmospheric loading of CO_2 and its consequences for the global climate can be supported by a precise understanding of its natural sinks and sources of CO_2, the major agent for global climate change. SO is a very appropriate region as it is least anthropogenically disturbed.

Data and Methodology: A hand-held five channel (340 nm, 440 nm, 500 nm, 675 nm and 870 nm filters) MICROTOPS-II sun-photometer was used to measure the aerosol optical thickness (AOT). The instrument measures AOT in the following wavelengths namely 340, 440, 500, 675 and 870 nm. Observations were taken on all cloud free days at half hourly intervals along the ship track. Meteorological parameters are continuously measured in one minute interval using AWS sensors (**Plate** 4). RM Young 61205V Barometric pressure sensor, Kipp and Zonen NR Lite Net Radiometer, Rotronic HygroClip temperature, humidity sensor and TM Young wind sensor are the sensors used in AWS. Apart from these scientific group from NCAOR, IMD and KBCAOS organizations has collected ocean-atmospheric data at 3 hourly (0000, 0300, 0600, 0900, 1200, 1500 & 1800 UTC) interval which includes dry bulb temperature, wet bulb temperature, sea surface salinity and sea surface temperature, wind speed, wind direction, atmospheric pressure, waves height, wave period, wave direction, clouds type, cloud amount of individual cloud, height of lowest cloud, present and past weather condition, visibility in meters together with ship parameter like latitude, longitude, ship heading and ship speed. Dew point temperature and relative humidity are calculated with the help of hygrometric table with respect to 1000 mb sea level. Coded message was prepare and transmitted globally with the help communication system onboard and finally IMD scientist filled MET-T-96 form.

In case of stable isotopes study, atmospheric water vapor are collected by PRL scientist with the help of liquid nitrogen traps (a glass line specially designed for vapor collection) is shown in **Plate** 5, the left panel show before adding liquid nitrogen gas and the right panel shows after adding liquid nitrogen gas. Ocean surface water collected at each degree latitude (**Fig**. 2) using clean plastic bucket and stored in 20 ml plastic bottles with tight-fitting using double caps to prevent evaporation, further these bottles taped at the neck for more protection. Atmospheric water vapor samples collected twice a day (1030 hrs & 2030 hrs) together with sea surface water sample (**Fig**. 3). In Table 1 gives details of sampling position during (a) onward journey and (b & c) return journey. To estimate salinity change in the past, 86 samples of sea surface water collected.

In selected location water samples at 12 depths were collected using CTD Rosette casts for the salinity and stable isotop analysis. **Table** 2 (a) and (b) show the positions where ocean water samples were collected at different depths (surface, 50, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000). Apart from this rain water samples (**Table** 3) were collected to verify Rayleigh isotopic fractionation over oceans. Snow samples and surface frozen ice sample collected for stable isotopic study are shown in Table 4.

The stable carbon isotopic composition of atmospheric CO_2 and dissolved inorganic carbon and pCO_2 of surface sea water will be used to find out the air-sea CO_2 flux. Discrete air samples (**Fig**. 3) have been collected to study the growth rate of atmospheric CO_2 in 1 litre glass bottles from the locations described in **Table** 5. The bottles are evacuated using a rotary pump and opened on the windward side of the ship at about 10 m above the sea level. To avoid moisture the air is allowed to enter the sample bottle through a U tube containing anhydrous magnesium per chlorate. For equilibration the bottles are kept open for about 10 minutes and then closed by means of high vacuum full Teflon stopcocks. The samples will be carried to laboratory. Concentration and stable isotope analysis would be done using gas chromatographic technique and mass spectrometer (MAT 253 with duel-inlet plus continuous flow set up). For stable carbon isotopic composition ($\delta^{13}C$) of dissolved inorganic carbon, about 15 ml water samples are collected from sea surface at each degree interval for both onward and return track. These samples are preserved in deep freezer at -20°C. The samples will be carried to the laboratory and CO_2 will be produced by reacting with orthophosphoric acid. The $\delta^{13}C$ of the produced CO_2 will be measured using a stable isotope ratio mass spectrometer (Duel inlet GEO 20-20).

Preliminary Results: Atmospheric parameters are useful for daily weather report as well as in predicting daily weather condition. The air temperature and dew point temp along meridional section, show decreasing trend towards south but not uniformly as shown in **Fig.** 4 (a, b). Stable isotopes study of surface water during SO (2006) shown that the region between 41°S and 45°S makes a demarcation between an evaporation/precipitation zone (north of 41°S) and a melting freezing zone (south to 45°S) as shown in **Fig.** 5. The sharpness of the transition zone could be dependent on season. Less slope of the δD - $\delta^{18}O$ line than 8.0 reveals that evaporation occurs in the SO under isotopic non-equilibrium condition i.e. kinetic effects (due to diffusion related fractionation) during vapor formation are more prominent. Future studies may throw light on the seasonal and spatial variations at above parameters in the SO. In future such experiments are required to verify these preliminary conclusions.

Vapor transport isotopic model is shown in **Fig.** 6 is depicted from Dansgaard, (1964). In most of the isotope based models it is assumed that vapor and ocean surface water are in isotopic equilibrium. It is not yet experimentally verified. The isotopic study is aimed at studying vapor-surface water isotopic equilibrium and to make an isotopic map for vapor over the

SO. **Fig.** 7 shows the variation of CO_2 concentration and the stable carbon isotopic composition in recent years from Australian Cape Grim baseline station (40.7° S. 144.7° E). A similar type of result can be expected from the present study as the growth rate of atmospheric CO_2 is continuously increasing. $\delta^{13}C$ will be located in the same line of the Keeling plot with an expected value around -8 ‰ with respect to PDB if there is no source of CO_2. If some source of CO_2 is there then this value will be depleted more. This result will be a very useful contribution for carbon cycle study and climate modelling.

b. Physical Oceanography & Simulation Studies

Scientific groups from NCAOR (objectives 1-3) involved in upper ocean dynamics and heat contents study and group from KBCAOS (objectives 4-7) (Allahabad University) concerned in simulation studies for which in-situ data have been collected.

Introduction: The ocean current system in the Southern Hemisphere is characterized by the presence of a strong eastward flow of the Antarctic Circumpolar Current (ACC). The ACC is one of the major surface current systems in the southern Indian Ocean. Many oceanic frontal systems of various water masses are embedded in the eastward-flowing ACC system and they have a key role in the modulation of prevailing hydrographic conditions. Knowledge of the frontal systems, current pattern and water masses within the SO need to be improved to enhance the predictive capability of the general circulation and climate. Climate trends can be studied by monitoring the rate of water mass formation. One of the major problems that hamper a comprehensive understanding of the dynamics of the SO is the scarcity of in-situ data in the Indian sector of the SO is non-uniform.

A General Circulation Model (GCM) study shows that the annual cycle of SST in the Indian Ocean is important in establishing the monsoon circulation and rainfall. Studies on SST, wind speed, relative humidity, precipitation and air temperature are sparse in the Indian sector of SO for all the seasons. Real time observations shall be carried out from the summer cruise. The surface heat and momentum fluxes shall be computed. Further the measured and estimated variables shall be compared with the reanalysis product.

Data and Methodology: For a better understanding of the SO frontal system XBTs and XCTDs were used. XBT probes (Make: Sippican; type: T-7; accuracy: ±0.15°C; depth resolution: 0.65 m), were launched from 27°30'S to 34°30'S at one degree interval (**Fig**. 8, **Table** 6). In frontal zone XCTD's manufactured by Tsurumi Seiki Company Limited (TSK) (type: XCTD-3; terminal depth: 1000m; temperature accuracy: ± 0.02°C and salinity accuracy: ± 0.03 mS cm^{-1}) were launched at 20 nautical mile interval from 35°S to 55°S (**Fig**. 8, **Table** 7) since the frontal systems are more prominent in this region.

Carousel Auto Fire Module (AFM) with portable CTD make: SBE 19 plus SEACAT profiler (accuracy: temperature ± 0.001°C, conductivity ± 0.0001 S/m and depth ± 0.005% of full scale) with accessory sensors (Oxygen Sensor: Make: SBE 43, Biospherical PAR light Sensor: Model No: QSP2300, WETLabs C-Star Transmissometer and WETLabs ECO Chlorophyll Fluorometer) was deployed at 2° interval (**Fig**. 9, **Table** 8) along meridional transect 57°30'E from 36°S to 56°S. Two deep casts were made at 54°S and 56°S and remaining cast were made upto 1000 m.

Onboard CTD with rosette sampler was used to collect water samples at different depths together with profiles for temperature and salinity (**Plate** 6). CTD's make: Neil Brown Instrument Systems, Inc. Mark IIIB CTD - Profiler (*Temperature:* range -32° to +32°C; accuracy (+/-) 005°C; resolution 0.0005°C, *Conductivity:* range 1 to 60 mmho; accuracy (+/-) 0.005°C; resolution 0.001mmho, *Pressure:* range 0 – 6500 db; accuracy (+/-) 6.5 db; resolution 0.1 db) with rosette samplers were deployed at 2° interval from 35°S to 57°S along 57°30'E meridional section (**Fig**. 10, **Table** 9). From 57°S onwards CTD cast was made in 1° degree interval and CTD with rosette sampler in 2° interval. CTD cast was operated continuously upto 66°S. During return across zonal section at 65°30'S, CTD was operated in one degree interval from 50°E to 57°E (**Fig**. 10, **Table** 10). Along 48°E meridional section CTD casts was operated from 62°S to 25°47'S in one degree interval and CTD with rosette was operated in 2° interval upto top 1000 m is shown in **Fig**. 10 (**Table** 11). During return journey from Mauritius to India (Goa), CTDs with rosette was operated in one degree interval is shown in **Fig.** 10 (**Table** 12).

Meteorological parameters collected at 3 hrs interval which is able to set the sensitivity of General Circulation Model (GCM) and would be performed with the real time observed forcing and initial conditions. The atmospheric variables collected during the cruise track will be utilized to estimate the bulk fluxes of heat, momentum and surface using the available bulk algorithms. Bottom topography of 5' resolution of terrain base will be used in both the models and interpolated to model grid. The POM Model will be initialized with the monthly climatology of Levitus (1994) atlas for temperature and salinity or any other available climatology. MOM3.0 will be initialized with Levitus (1982) atlas for temperature and salinity. The model will be relaxed to Levitus (1982) atlas for salinity and heat flux. *(These Data Sets will be taken from web resources)*

Preliminary results: The results obtained from the hydrographic data collected during 2006 in the SO when compared to the present studies would throw light on the significant changes occurring in the upper ocean thermal structure, heat content and ocean dynamics. This data is essential for the identification of different water masses, fronts and a comprehensive understanding of the strong current systems in the southern region. The vertical profiles of temperature and salinity has been plotted in **Fig.** 11 (a, b) at four stations, along 57°30'E meridional section at 35°31'S, 42°20'S, 47°40'S and 54°S to understand variability of temperature and salinity from different regions. Profiles were selected from subtropics, subantarctic and Polar Regions. **Fig.** 11a shows the sea surface temperature reduces towards south. In subtropics thermocline is observed and vanishes in the south. Temperature gradually decreases in deeper layer in tropics whereas in polar region temperature remains almost constant below 400 m depth. Pycnocline layer in top is observed in the polar region. Profiles of salinity in selected location are shown in **Fig.** 11b. Profiles show variation surface salinity and subsurface salinity in deeper depth as well as freshening of salinity towards south. A comparative study was done by deploying XCTD and pCTD at the same location. The profiles of temperature and salinity show good correlation is shown in **Fig.** 12 (a) & (b) at 46°S.

c. Chemical Oceanography

Scientific group from NCAOR (objectives 1-2) and PRL (objectives 3-4) were involved in studying the chemistry of the SO for which they collected various water samples from surface and subsurface regions. Basically their involvements in the study of trace metals and nutrients and TEI (Trace Element and Isotopes).

Introduction: The Earth's oceans contain a huge amount of carbondioxide in the form of bicarbonate and carbonate ions. The reactions between rock, water, and carbon dioxide produce bicarbonate. One example is the dissolution of calcium carbonate: $CaCO_3 + CO_2 + H_2O \rightleftharpoons Ca^{2+} + 2\ HCO_3^-$, such reactions tend to buffer changes in seawater CO_2. Since it produces an acidic compound, the p^H of sea water is thought to go down with increasing carbon dioxide levels. Reactions between carbon dioxide and non-carbonate rocks also add bicarbonate to the seas, which can later undergo the reverse of the above reaction to form carbonate rocks, releasing half of the bicarbonate as CO_2. Oceans can play a major role in the removal of excess CO_2 from the atmosphere by acting as a sink for CO_2. CO_2 is an important component of Earth's atmosphere because it absorbs infrared radiation at wavelengths of 4.26 μm (asymmetric stretching vibrational mode) and 14.99 μm (bending vibrational mode), thereby playing a role in the greenhouse effect.

The sea-surface carbon dioxide partial pressure has high spatio-temporal variability's in the SO due to large scale or local physical and biological processes. Trace metal concentrations in the open ocean waters are generally low. Antarctic waters have an abundance of inorganic nutrients in the water column but are characterized by low standing stocks of phytoplankton. In SO mixing of water masses takes place from nearby ocean basins which deciphering various sources of trace elements by characterisation and isotope distribution. The possible sources of trace elements of SO can be by the exchange of water masses from subtropical Indian Ocean from north, exchange of water masses from South Atlantic Ocean on the west and exchange from Pacific Ocean on the east. Furthermore, the Kerguelen and Crozet islands are other potential sources of large amounts of trace elements in SO. Other sources are small dust plumes from the deserts of Africa and Australia, and hydrothermal fluids from the mid ocean ridges, and the largest trace element fluxes are thought to be contributed from the Rodriguez Triple Junction.

Data and Methodology: Water samples were collected by the NCAOR to study the nutrients in the SO. During onward journey CTDs with rosette operated at different locations. Sampling was carried out at 2° interval from 35°S to 65°S upto 1000 m depth (0 m, 10 m, 20 m, 30 m, 40 m, 50 m, 60 m, 80 m, 100 m, 120 m, 150 m, 175 m, 200 m, 400 m, 600 m, 800 m and 1000 m) along 57°30'E meridional section as shown in **Fig.** 13 (**Table** 13a). During return zonal track along 65°30'S, subsurface water samples were not collected. Along 48°E meridional section water samples were collected from 65°S to 25°S in top 1000m depth (0 m, 30 m, 50 m, 80 m, 100 m, 150 m, 200 m, 600 m, 1000 m) and is shown in **Fig.** 13 (**Table** 13b). After port call at Mauritius on 26/4/09 vessel sailed to India. At one degree interval subsurface (0 m, 30 m, 50 m, 80 m, 100 m, 150 m, 200 m, 600 m, 1000 m) water samples was collected after crossing EEZ of Mauritius is shown in **Fig.** 13 (**Table** 13c). Apart from vertical sampling profile stations, surface water samples were collected in one degree interval (**Fig.** 2, **Table** 1 a, b, & c) along ship track. Time series observations were carried out near to Antarctic coastal water with varying longitude (**Table** 14). Following methods were used to store the surface water samples for different analysis at laboratory (**Plate** 7). The total inorganic carbon was measured by Coulometer (Model 5011, UIC Inc. USA). The analytical precision for the measurement was ±2µM. The accuracy of TCO_2 measurement was checked using the Certified Reference Material supplied by Dr. A. J. Dickson, Scripps Institute of Oceanography, USA. Dissolved Oxygen (D.O.) was measured by automated

Dosimat (Model 645- Multi Dosimat Hydro-Bios, Germany) high precision Winkler titrations. The precision of the measurement is ±0.01 ml. The water samples for trace metals were collected in dark colored 2 litre Amber bottles and immediately acidified upto $_{p}H_{2}$ using supra pure nitric acid (HNO_3). Further processing will be carried out in NCAOR laboratory and the samples will be analysed for total Trace Metals using ICP-MS. Nutrient determination will be done by the colorimetric method using the Autoanalyser (SKALAR). The method is based on the Beer-Lambert Law. The samples for nutrients were stored at (-20°C). $_{p}H$ was measured by using $_{p}H$ meter and also by multiple wavelength spectrometry using cresol red indicator. The total Organic Carbon (TOC) will be analysed by Total Organic Carbon analyzer back in NCAOR laboratory. The samples for TOC were acidified with ortho-phosphoric acid upto $_{p}H$ 3.0 and deep freezed at (-20°C). Air sampling was carried using compressor pump and the samples will be analysed for atmospheric carbon dioxide using Gas Chromatography.

For trace elements and isotopes (TEIs) study, waters samples was collected from surface at each degree along the ship track (**Fig.** 2, **Table** 1a, b & c). Also samples were collected from selected 5 stations shown in **Table** 15a for trace element and Nd measurement at the following depths: 5 m, 50 m, 100 m, 200 m, 300 m, 400 m, 500 m, 600 m, 700 m, 800 m, 900 m and 1000 m. **Table** 15b shows locations where 1 litre of water sample collected for trace elements. Similarly **Table** 15c shows locations where 1 litre of water sample collected for trace elements in selected location from Mauritius to India (Goa) ship track. The procedure is as follows (**Plate** 8), around 1.5 litre of seawater sample was collected in 2 litre plastic carbouy and filtered using 0.45 micron Millipore filter. Filtered 1 litre of seawater sample was stored in acid soaked Primary Productivity (PP) bottles in HCl medium (to $_{p}H_{2}$) by adding 2 ml of ultrapure 6N HCl. These samples will be carried back to the laboratory for measurement of TEIs using Inductively coupled Plasma-Mass Spectrometer (ICP-MS) and Thermal Ionisation Mass Spectrometer (TIMS). Another 60 ml aliquot of filtered seawater was stored in water soaked PP bottles and was kept unacidified. These samples will be taken back to the laboratory for analysis of isotopic composition of Boron using Negative Thermal Ionisation Mass Spectrometer (NTIMS).

For Neodymium (Nd) nearly 5-7 litres of seawater sample was collected and filtered through 0.45 micron Millipore filter paper and collected in another acid cleaned carbouy (**Plate** 8). The extraction of Nd from seawater was done by Fe co-precipitation method. The filtered seawater was acidified to $_pH_2$ by adding ultrapure HCl and 1 ml of pure Fe carrier. The samples was then shaken well and left idle for around 24 hrs for equilibration. After equilibration, NH_3 was added to the sample to raise the $_pH$ of the sample to 8-9 to precipitate Fe. The Fe precipitate scavenges the Nd from seawater and settles slowly within 8-12 hours. After settling of precipitate, the supernatant liquid was decanted and the Fe precipitate filtered through Whatman filter paper. The precipitate on the filter paper was re-dissolved in 6N HCl and collected in acid soaked 60ml PP bottle. These samples will be taken back to the laboratory for further chemical processing and measurement of Nd using Thermal Ionisation Mass Spectrometry (TIMS).

Preliminary Results: The atmospheric carbon dioxide increased tremendously in last few decades (**Fig.** 14). Expected outcome from two working groups are as follows. Measurement of CO_2 in the SO will help us to understand whether it is acting as a source or sink for atmospheric CO_2. The dissolved Oxygen, Nutrients, Trace metals, Total Organic Carbon, and $_pH$ measurements will reflect how chemical processes are regulating biogeochemical cycles in the SO.

The exchange of water masses using Nd isotopes has been done in the Southern Atlantic (49° 39`S, 33°23'W). Based upon the isotopic composition of Nd (ε_{Nd}), various water masses were identified in the vertical profile of the water column. The water masses identified in the study based upon their characteristic ε_{Nd} values were Antarctic intermediate water (AAIW) at the surface, Circumpolar water (CPW) at a depth of around 1000m, North Atlantic Deep Water (NADW) between a depth of 2000m to 3000m, Lower Circum Polar Water (LCPW) between 3000m to 4000m and Wedell Sea Deep Water (WSDW) below 5000m. The results for this study made in Southern Atlantic are shown in **Fig.** 15 Similar results are expected to be obtained in the Indian sector of SO.

d. Marine Biology

Scientific group from NCAOR (objectives 1-6), KBCAOS (objectives 7-9), PRL (objectives 10-14), CMLRE (objectives 15-16), and Karnataka University (objectives 17-18) are involved to study the Biological field of the SO for which they collected different quantity of sea water samples for different types of biological analyses. NCAOR looking for special distribution of phytoplankton, coccolithophores, estimation of chlorophyll and bacterial studies whereas PRL working on primary productivity as well nitrogen isotopes, CMLRE does the study of planktonic and benthic organisms considering the growing awareness about biodiversity in the global context and occurrence and distribution of various taxa, KBCAOS would be analyzing samples based on Nanophosphor application and Karnataka University does the studies on gelatinous zooplankton diversity and their abundance.

Introduction: The biodiversity & biological productivity of the SO is not widely studied from the Indian point of view. Marine phytoplanktons are important contributors to global carbon fluxes and thereby global carbon cycle. Ocean takes up considerable amount of CO_2 through physico-chemical and biological processes and acts as a "sink" of atmospheric CO_2; oceanic biota plays a major role in this process. Phytoplanktons are present in the upper sunlit layer of the ocean called as euphotic zone. In the presence of sunlight they convert inorganic CO_2 into organic carbon through photosynthesis. A major part of this primary production is recycled in the euphotic zone itself, through microbial decay or is eaten by zooplankton, and thus enter the food web Nitrogen isotopes can be used as an important tool to estimate the export of carbon out of the surface ocean.

Phytoplankton succession and community composition reflect the environmental conditions of the ecosystem, among which the availability of nutrients play a significant role. Chlorophyll 'a' is responsible for fluorescence property of phytoplankton. Different types of chlorophyll types like Chl 'a', Chl 'b', Chl 'c' indicate the presence of different phytoplankton groups whereas phaeopigments indicate dead parts of phytoplankton so chlorophyll estimation will also provide the composition of phytoplankton. Due to high nutrient low chlorophyll (HNLC) characteristic of SO, it is important to understand the composition and spatial variation of phytoplankton and chlorophyll. The coastal area of SO is a fluctuating environment due to influx of fresh-water from melting icebergs. Fresh-water input changes the salinity which results in low productivity in this region. In this situation, it is important to understand the time series observations for phytoplankton.

Studies have shown that gelatinous zooplankton of the ocean serves as important food source for many marine animals particularly the leatherback sea turtles, *Dermochelys coriacea.* These animals are also known for their migrations into the SO, 600 kms down south of the Aghulas Basin. However the migrations are sporadic, despite the high cold tolerance ability in the leather backs. Understanding the gelatinous plankton diversity in the Indian Sector of SO, a relatively less studied area, among other contributions, could enhance current knowledge on the migrations and conservation of these endangered turtles.

Also bacteria are considered as major agents in the cycling and mineralization of organic carbon in the sea, and are thus important in the context of marine food webs as well as in the global carbon cycle. Coccolithophores are important photosynthetic organisms made of $CaCO_3$. Their presence is comparatively less in SO due to higher latitude and carbonate compensation depths therefore it is important to understand their spatial variation. To decipher paleoceanography and past climatic changes, diatoms are potentially used. They are useful as biostratigraphical zone fossils in marine deposits from high latitudes or at deeper water depths, both of which lack calcareous microfossils. Diatoms are most successful photosynthetic organisms due to which they are dominant marine primary producers and contribute approx. 20% of annual primary productivity. SO is HNLC region in which it is important to understand the dissolution (Biocoenosis) and preservation (Thanatocoenosis) of diatoms. Diatoms are the most abundant micro-algae which are responsible for 40% carbon fixation in the ocean via photosynthesis. Diatom cells have a range of features that make them highly divergent from the classical cellular structures of higher plants and animals. Of particular interest is the diatom cell wall, composed of amorphous silica molded into species-specific nanometer scale structures. Understanding and subsequent exploitation of the mechanisms by which diatoms are able to fabricate such structures at ambient temperatures and pressures may have significant applications in nanotechnology.

Data and Methodology: For fulfilling studies on Phytoplankton, Coccolithophores, Chlorophyll estimation at bacterial studies, water samples were collected as follows. The vertical profile of sea water collected in two degree interval is shown in **Fig.** 13. Surface sea water sampling is done every degree (**Fig.** 2) from Mauritius – SO - Mauritius cruise track. Sampling carried out from 35°S onwards to 65°S upto 1000 m depth. The depth levels selected for collection of water sample were 0 m, 10 m, 20 m, 30 m, 40 m, 50 m, 60 m, 80 m, 100 m, 120 m, 150 m, 175 m, 200 m, 400 m, 600 m, 800 m and 1000 m along 57°30'E meridional section and is shown in **Table** 16a. During return track sampling started from 65°S to 32°S along 48°E meridional section in top 1000 m depth. The depth selected were 0 m, 30 m, 50 m, 80 m, 100 m, 150 m, 200 m, 600 m, 1000 m along meridional section 48°E is shown in **Table** 16b. From Mauritius to India (Goa) cruise track, similar pattern of sea water sampling continued in one degree interval is shown in **Fig.** 2 and **Fig.** 13. **Table** 16c shows sampling location of subsurface water sampling. **Plate** 9 shows the filtering of water samples using vacuum pump.

Phytoplankton samples were collected using Multi-plankton Net (Hydrobios, Kiel, Germany) of 10μm mesh size net at 35°S, 37°S, 39°S, 41°S, 43°S and

45°S in ongoing track from surface to 200m water column (**Fig.** 16). Surface samples for phytoplankton has been collected through the bucket and filtered using 10μm net from 46°S to 66°S in ongoing track and 65°S to 25°S in return track in one degree interval (**Fig.** 2) and from Mauritius to India (Goa). All the samples have been preserved in buffered formalin and further analyses would be carried out at laboratory for further microscopic studies. For coccolithophores study water samples have been collected from standard depths (0m, 50m, 100m, 150m, and 200m). Samples have been filtered through 0.45 μm Millipore filter paper and wrapped in aluminum foil for further microscopic studies. For chlorophyll estimation, water samples were collected from 13 depths viz. 0m, 10m, 20m, 30m, 40m, 50m, 60m, 80m, 100m, 120m, 150m, 175m and 200m in ongoing track and from 7 depths viz. 0m, 30m, 50m, 80m, 100m, 150m and 200m in return track. All samples were filtered through GF/F filter paper. While filtering the water few drops of magnesium carbonate was added to prevent acidity of samples. Filter papers wrapped in aluminium foil and kept in deep freezer (-20°C) for further analysis. The samples will be analyzed by spectrophotometric method in lab.

For bacterial studies samples were collected from 13 depths viz. 0 m, 10 m, 20 m, 30 m, 40 m, 50 m, 60 m, 80 m, 100 m, 120 m, 150 m, 175 m and 200 m during ongoing track and from 7 depths viz. 0 m, 30 m, 50 m, 80 m, 100 m, 150 m and 200 m. 500 m water sample was collected from each depth and filtered through 0.22 μ filter paper for ATP analysis. Around 50 ml water sample was stored in -20°C to study the abundance, viability and culturability of oceanic bacteria and 5 ml of water was preserved with buffered formalin for studying direct count of bacteria. Samples for ATP will be analyzed for total bacterial luminescence on luminometer. Bacterial counts will be done by using AODC. Sediment samples were collected and preserved in -20°C to study the microbial activity in deep seafloor sediments. Time series observations (12 stations in three days, **Table** 17) were carried out for phytoplankton in Antarctic coastal water with varying longitude and apart from the surface water samples, surface sediment samples were collected for diatom studies at four stations (66°10'S 57°31'E, 66°08'S 57°18'E, 65°54'S 57°02'E, 65°30'S 54°E).

For nanophosphor application ~ 2 litre of surface seawater sample and about 2 litre of seawater from different depth (0 m, 50 m, 100 m, 200 m, 300 m, 400 m, 500 m) were collected in 2 litre plastic carbouy and filtered (**Plate** 10) using 0.45micron Millipore filter paper (**Table** 18 a, b, c) along ship track (**Fig.** 1). The filter papers were then stored and will be analyzed at Nanophosphor Application Centre, University of Allahabad. Samples from sea surface were collected from each degree along the track (**Fig.** 2).

Primary productivity (PP) measurements were carried using C^{13}-N^{15} coupled tracer technique. Water samples were collected is shown in **Table** 19 (a, b & c) along the ship track (**Fig.** 1) at 6 different depths, corresponding to 100m, 80m, 64m, 20m, 5m and 1% light levels, to cover the entire euphotic zone. Samples were collected using Go-Flo and Niskin bottles attached to a CTD rosette sampler (**Plate** 11). Individual samples were taken, in duplicates, in polycarbonate Nalgene bottles: for C^{13} uptake rate measurements samples were collected in 1 litre bottles and for C^{13}-N^{15} coupled tracer method different samples were taken for measurement of nitrate (2 litre volume), ammonium (2 litre) and urea (1 litre) uptakes rates. This was followed by addition of ^{13}C and ^{15}N enriched (99 atom %) bicarbonate, nitrate, ammonium and urea tracers to individual samples taken for measurement of carbon, nitrate, ammonium and urea uptake rates. Samples were then incubated on the deck after putting on neutral density filter to simulate the light levels from which the samples were collected. Sea water was continuously circulated during the incubation to maintain the temperature. Samples were incubated for 4 hrs symmetrical to the local noon. All samples were filtered subsequently through pre-combusted (4 hrs at 400°C) 47mm diameter and 0.7μm pore size Whatman GF/F filter, dried in oven at 60°C overnight and then preserved for mass-spectrometric analysis on shore. Samples were collected at one degree interval from 26°S in two litre bottles and filtered through GF/F filter, dried in oven overnight at 50°C and preserved for $\delta^{15}N$ analysis. This will help understanding nitrogen biogeochemistry of the SO.

To study the planktonic and benthic organism following procedure was followed. For phytoplankton study water samples (10-15 litres) were collected from the surface at 9 stations and filtered through a 20μ mesh filter. They were then preserved in formalin. Also water samples (1 litre) were collected from fixed depths (10 m, 20 m, 30 m, 50 m, 80 m, 100 m & 120 m) from the CTD Rosettes (**Fig.** 13) and preserved in formalin & Lugol's iodine together with surface water (1 litres). For micro-zooplankton study, water (5-8 litres) from the fixed depths and surface sea water were filtered using two nets of mesh size 200 **μ** and 20 **μ**. The sample retained in the 20 **μ** mesh was back washed and preserved in formalin and Lugol's iodine. Water samples (125ml) were also collected (**Fig.** 13) from the fixed depths (10 m, 20 m, 30 m, 50 m, 80 m, 100 m, 120 m, 200 m, 400 m, 600 m, 800 m and 1000 m) for the analysis of dissolved oxygen (**Table** 20). Details of sampling are shown in **Table** 20 (a, b & c) along ship track.

Muti-Plankton Net (MPN) was operated is shown in **Plate** 12 (**Fig.** 16) for meso-zooplankton at 6 stations for vertical sampling of meso-zooplankton upto a depth of 200m. The samples collected were preserved in formalin. Using Bongo Net of 200 mic operated in 15 stations (**Fig.** 16, see details in **Table** 20 (a, b & c). It was hauled at 2 knots ship speed for 10 minutes. During the operation, the volume of water entering the net was monitored using the flow meter attached to it. The samples collected were preserved in formalin. To carry out molecular level studies, organisms were preserved in alcohol at selected stations. For benthos studies, grab was operated at eight locations (**Fig.** 17, see details in **Table** 21). Samples were collected for macrobenthic and meiobenthic studies (using hand corer) along with samples for particle size analysis and organic carbon analysis.

Scientist from NCAOR, CMLRE & Karnataka University shared zooplankton sampled collected using Bongo net (**Fig.** 16, **Table** 22 (a & b), and the same preserved in buffered formalin and 99% ethanol (**Plate** 13). Separate plastic bottles were maintained for formalin and ethanol preservation Formalin preserved samples will be used for general taxonomic studies and Ethanol preserved samples will be used for molecular studies. Day or night samples have been collected as per the feasibility of collection. Samples collected will be analyzed qualitatively and quantitatively in lab. A number of surface sea water samples have also been collected, particularly during rough weather, where Bongo nets could not be operated.

Preliminary Results: Quantification, community composition and spatial distribution of phytoplankton would provide information on the structure and dynamics of marine ecosystem. Chlorophyll estimation would provide information about phytoplankton presence through the different chlorophyll pigments and phaeopigments. The spatial distribution of diatoms in the sediments will be used as a valuable tool to infer the recent past climatic changes. Biocoenosis and thanatocoenosis of diatoms will provide information - how much amount of dissolution and how much amount of preservation is there in SO. The vertical distribution, abundance, viability and culturability of bacteria will be useful to understand the structure of marine ecosystem with respect to bacterioplankton.

An interesting observation includes the abundance of unidentified spindle shaped plankton in the Bongo net from 61°S latitude in the onward track. The same was observed in the cross track and return track. The major groups of zooplankton observed were copepods, amphipods, decapod larvae, hydrozoans and salps. However, no euphausids (krill) were observed in the bongo samples. Organism such as jellyfish were obtained using bongo net are shown in **Plate** 14. Diversity and abundance of planktonic forms particularly the gelatinous type was observed along the cruise track in the Indian sector of the SO.

Nitrate, ammonium and urea uptake rates were measured in the Southern Indian Ocean during the late austral summer, 2006 is shown in **Fig.** 18. New production and f-ratio exhibited significant spatial variation: higher uptake rates at coastal and equatorial regions and lower uptake rates over a large area in the SO. Our measurements show that although the productivity over a large area of the SO is low, the f-ratio is moderately high (0.53), with an upper limit of 0.63. On the basis of the present study along with the previous results we will be able to characterize the different active biological provenances in the SO. This subdivision can help in calculating carbon sequestration over a large area using ocean color data. Also, f-ratios are useful to estimate the export flux and to generate new production maps for this region using satellite data.

e. Geology

Expedition members from NCAOR, KBCAOS (Allahabad University) and Goa University were occupied to study the geological aspect of the SO.

Introduction: Suspended matter generally comprises of inorganic and organic particles which is suspended in the water column, either permanently or temporarily. Salinity and temperature maintain significant relation with suspended particulate matter (SPM). Foraminifera is a large group of amoeboid protists with reticulating pseudopods, fine strands of cytoplasm that branch and merge to form a dynamic net. They typically produce a test, or shell, which can have either one or multiple chambers, some becoming quite elaborate in structure. Calcareous fossil foraminifera are formed from elements found in the ancient seas they lived in. Thus they are very useful in paleoclimatology and paleoceanography. They can be used to reconstruct past climate by examining the stable isotope ratios of oxygen and the history of the carbon cycle and oceanic productivity by examining the stable isotope ratios of carbon. Geographic patterns seen in the fossil records of planktonic forams are also used to reconstruct ancient ocean currents. The oceanic carbonate system is intimately linked both to atmospheric CO_2 and the global carbon cycle, it is very important to study foraminifera. Organic carbon content of sediments reflects the overhead paleoproductivity therefore it is important to explore the amount of organic carbon drawdown to the deep sea. The vessel proceeded towards up to Enderby Land (up to 66°10'S & 57°30') where we have started Van veen Grab samplings. The Enderby Landmass intrudes into the ocean (shelf) being embedded by Prince lave coast and Kemp coast. The Grab sampling was performed in restricted region of that shelf due to paucity of time. Intensive sampling was not possible due to icebergs and time constraints of ship schedule.

Material and Methods: For analyses of suspended particulate matter, member from Goa University colleted sea surface water samples in one degree interval starting from 28°S up to 66°S covering three main zones that is Sub-tropical, Sub-Antarctic and Antarctic zone. CTD profiles for the track selected at specific locations is shown in **Table** 23a during onward journey and **Table** 23b during return journey at 35°S, 40°S, 41°S, 43°S, 55°S, 59°S, and 65°S. Vertical profiles of water samples collected at specific depth (surface, 100 m, 200 m and 1000 m) are shown in **Fig.** 17 (square box). At each depth 5 litres of water sample was collected and filtered with pre weighed millipore filter paper of size (0.45 um) and was wrapped and kept in aluminum foil for further analysis which will be carried out in laboratory (**Plate** 15). Results obtained will be compared with those of 2006 SO cruise to see whether any changes have taken place in past years.

Also 25 litres of sea surface water samples were collected twice in a day (one before sunrise and one during a day) for doing experiment - 1 and experiment - 2. In experiment – 1, water samples are filtered (25 litres) using GF/A filter paper (both dark and light samples). GF/A filtrate paper were stored in duplicates in deep freezer. In experiment – 2, formaldehyde was added to the water sample and incubation was done at 4°C. After completing 12 hours incubation period, phosphate buffer solution was added and filtered using GTTP filter paper. Filter paper was then kept in Eppendroff tubes and wrapped with parafilm and stored in deep freezer. In total, water sampled from 23 stations were collected during return track in light and dark light (**Table** 24). Further analyses will be carried out in laboratory.

Besides these samples were collected for NIO at specific latitudes (63°S, 61°S, 59°S, 55°S, 39°S, 35°S) during return journey. The depths of the interest were 100m, 200m, 600m, 800m and 1000m together with sea surface water samples. Water was collected in PP bottles around 500ml in duplicate along the track and stored in deep freezer.

To understand changing climatic condition NCAOR collected surface sediment samples at four stations for microfossil, sedimentological and geochemical analysis (**Fig.** 17). **Table** 25 shows details of sediment collected using gravity corer (**Plate** 16, left panel) and **Table** 26 shows the details about surface sediment collected using grab sampler (**Plate** 16, right panel). Small portion of the sediment sample was stained with Rose Bengal in order to distinguish between the living and dead foraminifera and other portion of sediment sample was dried in oven at 60°C in order to carry out organic carbon analysis. Sediment foraminiferal analysis and grain size analysis will be carried out back in lab using pipette analysis method.

Further sedimentological study will be carried out by NCAOR as follows. Size analyses of the sediments would be carried out for sand, silt, clay ratio and their statistics (Carver 1971). Organic matter and calcium carbonate would be estimated to know about the source of OM and Ca Co3 Mineral identification (after slide preparation) will be done to establish any presence of relict minerals and carbonate deposits like Oolites or Pellets etc (in the Antarctica shelf) which in turn may give some clue for the existence of Paleo-strand lines of Pleistocene as reported in other shelves. Chemistry and clay mineralogy (as per Biscay semi-quantification method) would be dealt to decipher the sediment characteristics from where they were derived in the Sub-Bottom Profiling of the Parasound Atlas onboard would be taken into consideration (details about system is given in next section) viz. depth of penetration, sediment characteristics, frequencies of the contrasts between the successive beds. Grab samples collected at 8 locations (**Table** 26), which was very close to Antarctica land. Types of sediment were mostly Sandy-clayey type and were also with many sea organisms. The latitude and depth at which grab was operated is mentioned in table below.

Preliminary Results: The Spatial distribution of foraminifera will be used for estimation of paleo-oceanography. Their isotopic composition will reveal the paleo-temperature and paleo-productivity. Grain size composition will reveal the transportation and provenance of sediment grains in the SO. Variation compare to 2006 data has occurred due to climatic changes in past four years whether any change has resulted due to increasing climatic changes in past few years. Relict minerals and oolites are expected in the study shelf region of the continent. The carbonate deposition might have been taken place due to shallow water agitated condition during Pleistocene. The existence of Paleo strandline of Pleistocene is expected around 200m to 300m water depth. The exposed sand patches (Pleistocene period) would further suggest that this shelf region is starved of sedimentation since Pleistocene. The absence of drainage system in this part of the continent have been attributed to the geomorphological features in the Enderby Land which has intruded into the ocean between Prince Olava coast in the west and Kemp coast in the East. The results observed needs to have detailed sedimentological / micropaleontological investigations along with isotopic study. Echinoderms including Sea lilies (**Plate** 17) and Brittle stars (**Plate** 17) were observed in the benthic grab sample. Also Decapods (crabs) were present in benthic sampler.

f. Geophysics

Scientific group from NCAOR interested to collect underway data from hydrosweep swath and Parasound sub-bottom profiler along the ship track to understand topography features in the SO and to explore the sedimentary type.

Introduction: The presence of geophysical data from Hydrosweep swath and Parasound sub-bottom profiler in SO is not adequate. Expedition members took this opportunity to collect underway data using Hydrosweep swath and Parasound sub-bottom profiler. The bathymetric survey and sediment profiler are run to obtain information about the seafloor topography as well as thickness and structure of the upper sedimentary cover. The concept of multiple narrow-beam depth sounding has come into reality with which 100 % coverage can be assured.

The main characteristics of the Atlas Hydrosweep DS-2 equipment is the large sector of 120° covered by a fan of 59 or 118 preformed beams (240 beams with HDBE). This is possible without drastical loss of accuracy due to a patented real time CROSS FAN CALIBRATION METHOD. The ATLAS HYDROSWEEP DS-2 operates with a transmission frequency of 15.5 kHz. The maximum depth is in access of 10,000m within a swath angle of approximately 60°. At 8000m water depth, the specified coverage is 90° and at 4,700m water depth the coverage is specified for 120°. The minimum depth, still with 120° coverage is 10m for shallow water operation. The swath width with 120° is approximately 3.7 x water depth for 10 – 4, 700m; with 90° is approximately 2 x water depth for 10 – 8,000m; with 60° is approximately 1.5 x water depth for upto 11,000m.

The ATLAS PARASOUND seafloor survey system presents state-of-the-art multifunctional echo. Atlas Parasound sediment echosounder is a hull mounted system for high resolution acoustic studies of geological section of the sea floor. The ocean water depth capability ranges from 10 to 10,000m. The acoustic signal focused like to a cone with an opening angle of 5° which is capable of penetrating sediment upto 200m depending on sediment type. The high angular and vertical resolution provides information on optimal stratigraphic layer identification and morphological features. The primary frequencies, which are used to generate the low frequency in the water, were designed to be 18 kHz (fixed) and 19.0 kHz - 23.5 kHz switch-able in steps of 0.5 kHz. The fixed primary frequency allows the system to reach full ocean depth, with a second primary frequency which is operated selectable to generate a secondary frequency between 2.5 kHz and 5.5 kHz. A pilot pulse is first transmitted to determined actual depth of the seabed. The system processor then determines how many pulses will fit into the travel time at that depth and emits a suitable train of pulses. This sequence is then repeated and corrected with the measured depth automatically. This approach greatly enhances the resolution of small scale features such as sedimentary bed forms. In this system, the electronic beam steering techniques are applied for stabilizing the sound beam against the vessel's rolling and pitching movements.

Material and Methods: Data collected with the sediment echosounder Parasound recorded with digital data acquisition system and the multibeam swathsounder Hydrosweep DS-2 (both designed and build by Atlas Electronics) Both systems are permanently installed on the R.V. A. Boris Petrov.

The Hydrosweep DS-2 system: Sound velocity is calculated using Sound Velocity Profiler (SVP) which is operated in top 1000m water column. Sometime sound velocity profile is calculated using temperature and salinity values obtained from CTD cast. Sound velocity data feed into the Atlas Hydromap online operating system which provides online Hydrosweep swath map. Hydrosweep makes used of a unique, patented calibration process, which takes place while the vessel is underway (**Fig.** 19). During data acquisition, system by itself calculates mean velocity of sound by means of two special techniques provided in Hydromap online system. By means of calibration method, the mean velocity of sound is determined over the water column. Sound refraction effects in the slanting beams are compensated. In the calibration mode, the transmitting and receiving functions of the system are swapped between the two hydro-acoustic transducer arrays. In calibration mode the 59 Depth values can be measured parallel to the ship's longitudinal axis. The frequency is high enough to secure good vertical resolution, even in shallow water, and the signal is reflected from the true bottom, rather than penetrating the sediment layers to the sub bottom surfaces.

Further the acquired data is processed using offline Hydromap operating system. The main modules of Atlas Hydromap offline have a full user interface. Some of them can be adjusted in size and location, others just in their location, in order to get access to the screen background where the icons are located. Closing and opening windows takes place by operating the corresponding buttons of the dialogs/menus inside of the windows. **Fig.** 20 shows all available graphical components of the user interface of Atlas Hydromap offline. The graphical user interfaces of calling modules will be iconized as long as subsequent modules as active. The icons are located in the lower left corner of the screen background. After having closed subsequent modules the window will be restored automatically. The processing includes correction of navigation data and automatic as well as interactive editing had to be carried out manually and carefully because of artifacts, which are on the same scale as the topographic features in the study area. For display the data were gridded after editing. The two dimensional map are produced using graphic software. One such example of multibeam survey map is shown in **Fig.** 21 (a & b) obtained during cruise period.

The Parasound system: The received data was digitized and stored with the ParaDigMA software for further digital signal processing and display. Atlas

Hydromap server monitor displays online Parasound profile with time. During Data Acquisition the .asd-files from the Control Unit PC are transferred to the Parasound PC and that the data is visible with Parastore-3 (PS3). The PS3 data converted to a standard seismic data format named SEG-Y. For this, a small tool is provided, working with Windows, HP-UX, Sun Solaris and Linux operating system. Figures were scaled from two way travel time to depth for a constant sound velocity of 1500 m/s. Further maps are produced using image processing software. Some of the examples of sub bottom profiler during cruise period are shown **Fig.** 22.

Preliminary Results: Underway geophysical data was collected all along the cruise tracks in the SO. Multibeam data could not be acquired during return track in the SO due to system failure. The underway Hydrosweep swath and Parasound data was obtained outside territorial waters. Multibeam survey block was made from 6°45'S to 8°00'S and 62°00'E to 62°09'E before operating gravity corer as well as testing of multibeam after it got repaired at Mauritius.

The information will be obtained about the seafloor topography as well as thickness and structure of the upper sedimentary cover using bathymetric survey and the sediment profiler along ship track. The Parasound data reveals thick zones of high reflectivity at or directly beneath the sea floor. The zones are discontinuous and covered by 5 m thick transparent sediment drape as shown in the Parasound record (**Fig.** 23). Both, the high surface reflectivity and the kind of draping, are not typical for sediment of SO. The figure also indicates that the zone of high reflectivity follows the layering and reveals a sharp base.

g. Astronomy

Scientist from Karnataka University interested to collect data of night sky observations for unidentified light phenomenon in the Indian sector of the SO.

Introduction: Observations of the night sky, at different latitudes was carried out in order to confirm, if any, the illuminating activities of unidentified flying objects. Significant data on these light phenomenons have been recorded and verified with related institutions, for the last 6 years along the entire Indian coast line. The SO region is of particular interest as it lacks satellite activities at specific latitudes, and is highly distanced from the developed world, a factor, which helps eliminate, impact (or reduced effect) of human induced illuminations in the night sky. The observations can throw more light into the occurrence of UFO activities, or alien life, if existing, over the Indian subcontinent and other parts of the world.

Material and Methods: Night sky observations was carried out during clear skies and safe weather conditions. Moving and illuminating objects were spotted with naked eyes so as to mark the location of activity. Specialised tracking devices can be used in the subsequent stages. Time duration spent on the monkey deck was between 30-60 minutes, one to two hours after sunset with 1 or more participants of the SO expedition. Magnetic compass or wind vane (at times) has been used to determine directions.

Preliminary Results: Of the 20 night sky observations carried out to date, 5 observations (**Table** 27) coincided with the unidentified illuminations prerecorded from the Indian subcontinent. Total no of moving objects recorded is 35. Of this 7 resemble that of meteoritic activity (commonly called shooting stars), 22 of satellitic nature and 6 of the unidentified night sky illuminations. No planes or lights resembling such were identified during night sky observations along the southern ocean cruise track. Critical study will be generated which will add to the database on illuminating and unidentified moving objects in Indian science.

9. Performance of the Equipments & Ship

Section – 6 gives the list of various types of equipment used/operated during SO expedition - 2009 to accomplish multi-disciplinary objectives. Atmospheric parameters were measured using Sun-photometer, handheld meteorological equipment and continuous Automatic Weather Station (AWS) sensors. Performance of the equipments was reasonable good. During rough weather air frame of radiation sensor got bent and cable was broken for which time data is missing from radiation sensor. Measurement of sea surface temperature using Bucket thermometer was satisfactory except during the bad weather when data could not be collected in a few stations.

MK-21 system was used to launch XBT and XCTD probes to collect temperature and salinity profiles in top 1000 m without stopping the vessel. Initially system performance was all right but in between launching probes gave some errors due to faults. After crossing latitude 60°30'S along meridional section 57°30'E system failed to work w.e.f. March 2nd, 2009. Sippican make MK-21 USB DAQ started giving the trouble. The following message appeared on screen MK21 I/O- Load Driver and "Unable to access the MK21-USB device. Please ensure that the MK21-USB device is connected". Because of this, high resolution hydrographic profiles could not be collected on return track along 48°E meridional section.

Carousel AFM attached with portable CTD which was operated at 2° interval along ship track failed to trigger niskin bottles at selected depth. However, other sensors of portable CTD for measuring temperature, salinity, oxygen, Biospheric PAR, Transmissometer and Chlorophyll Fluorometer profiles worked well. On 28th February 2009, AFM with portable CTD operated without niskin bottles at station position 56°00'S, 57°30'E for deep cast. At 1400hrs deep sea winch suddenly stopped due to unknown reasons. During this period, sea was very rough and wave height increased to 10-15m. AFM unit (with portable CTD) was rolling and swinging with severe waves for more than 10min. The wire rope of deep sea winch (18mm) was retrieved without AFM unit (with portable CTD) and connected shackle. AFM unit (with portable CTD) got detached; breaking the shackle from the wire rope (could be due to entangling with wire cable). There were bends and kinks at 20 places (**Plate** 2) on the wire rope of ~33 metre; might be due to looping and entangling of wire rope around AFM unit. Also, white paint (of AFM unit) was observed at the places of bends and kinks of the wire rope due to scratching and entangling. However work continued with ship borne CTD to fulfill the objectives of the multi-disciplinary expedition members.

Neil Brown instrument system Mark IIIB CTD profiler with rosette was deployed every degree along the cruise track. Hydrographic parameter such as temperature and salinity profiles along with sea water samples were recorded as when required. The performance of the Mark IIIB CTD was very good and fulfilled the maximum requirement as far collection of data to achieve the objectives of the expedition was concerned. The CTD Rosette operated with 30 litre Goflow Niskin bottles which failed to close due to defect in closing mechanism. This resulted in increased numbers of CTD casts for water sampling. Goflow Niskin bottles are too old to be used with recent technology hence non functional and should be disposed off. During one of the CTD operations while heaving up CTD with rosette, big swells forced unit frame to hit sidewall of the ship breaking and damaging the Niskin bottles (four 5 litre, one 30 litre and four 1.7 litre) (**Plate** 3).

Electric brake control unit of CTD winch started giving trouble from 4/3/2009 thereby not possible to stop winch in between with control unit. These problems appeared first time when CTD was operated for deep cast at 65°30’S, 57°00’E. The wire rope was released from the winch with full speed and difficulty faced to stop the winch. Since spare parts of the break were not available, temporary arrangement of stopper were made with nut to stop the winch manually reducing the winch speed. The stopper was breaking while stopping the winch manually. The team effort was to make the operations safe and operational to progress. Hence decided taking concerned of electric engineer, master of the vessel and chief of expedition onboard, not to operate CTD beyond 1000m. Electric break winch problem was rectified on arrival back to Mauritius.

On 17th March 2009 problem encountered in cable connection between CTD and CTD deck unit, were rectified and CTD was made operational and niskin bottles could not close. There was still problem in triggering mechanism and fault found in CTD cable and computer. Cable was cut around 400m and system made ready for operation. At the time of CTD operation protection frame broke down. Winding of cable took place automatically pulling the CTD unit from the main frame. Subsequently frame has been repaired and system mounted back on frame for operation. Later also found fault in the cable as result total CTD cable cut from CTD winch was around ~1400m.

Surface salinity measured using AUTOSAL was calibrated with standard sea water capsules. Initially AUTOSAL was working fine but later due to cold temperatures there was problem to fixed AUTOSAL to room temperature. Supplementary AUTOSAL inaccuracy was rectified and worked satisfactory afterwards. Titration - Dosimat unit, Columetric meter, Vaccum pump, Barnstead dlamond water system, Barnstead dlamond storage reservoir, Milli-Q water purifier, p^H meter, Auto clave, Oven, Hot plastes, Spectrophotometer were functioning satisfactory. During rough weather condition, spray of sea water entered through the port hole inside the laboratory where spectrophotometer was kept for doing analyses which was stopped functioning due to contact with sea water.

Bongo net belonging to CMLRE was satisfactory and was operated throughout the cruise except during rough sea condition when one set of net with bucket was lost. Multi-Plankton Net (MPN) was operated as and when required without triggering mechanism in top 200 m depth. Two nets got damaged due to strong waves.

Gravity corer and Van veen Grab (big & small size) mechanism was satisfactory except that there was a problem with deep sea winch when Gravity corer operated at station 59°S, 57°30'E, depth around 5100 m. The deep sea winch stopped working on 1st March 2009 around 1430 hrs when gravity corer touched the bottom. Mechanical engineers tried their best to repair the winch. They found damage in the hydraulic part which could not be replaced nor repaired onboard.
The Russian Chief Scientist and Captain with the concerned of the ship owner decided to cut the deep sea winch cable of 18mm approximately 5100 m in length. The ship located was noted as 58°55.5'S, 57°03.3'E at 2300 hrs. Due to breakdown of the deep sea winch gravity corer could not be operated.

Initially Hydrosweep swath (Atlas DS-2) multibeam system was switched on power after crossing territorial water of Mauritius. Acquisition of underway bathymetric swath was satisfactory along ship track. Multibeam system stopped acquisition of data from 23/02/2009 at 0430 hrs of GMT due to technical problem. Since multibeam stopped working Hydrosweep swath of the SO is missing. Scientist tried their best to repair the multibeam system but due non availability of spare PCB which was damaged could not be replaced with new PCB to make the system functional.

Atlas Parasound sub bottom profiler was switch on after crossing the territorial waters of Mauritius. The performance of the equipment throughout the cruise was very good. The acquisition of underway data along the ship track provided information on morphological features and characteristics of the sediments.

During port call at Mauritius on 26th March 2009, deep sea winch and Atlas Hydrosweep DS2 were repaired by the expert engineers from respective companies. On the return track from Mauritius to India (Goa), multibeam system was tested at 1630 hrs IST, and was found to work satisfactory. Deep sea winch was rested around 1710 hrs IST, and was found working. On 29/03/09 early morning multibeam system was tested together with German Engineers and it was found to be satisfactory. The deep sea winch tested together with Russian engineer for mechanical functioning by releasing wire from winch and winding back on winch. This procedure repeated 4 times for satisfactory performance of winch. Completing both the tests, engineers left the vessel by small boat and ship sailed to India. On return track gravity corer operated after loading new wire of 16 mm about 1000 m and 12 mm about 1000 m added to 18 mm wire of 1300 m (spare 9.6 mm two spools of 3000 m was available. In general, the overall performance of the shipboard machinery and equipment used was satisfactorily for satisfying the objectives of the multidisciplinary cruise. We could not off-hire the vessel in between cruise period in open seas to satisfy the other aspect of the expedition members.

9. Preliminary Results

Some of the preliminary results obtained during Southern Ocean Expedition are given below: The air temperature and dew point temp along meridional section, show decreasing trend towards south but not uniformly. Isotopic study is aimed at studying vapor-surface water isotopic equilibrium and to make an isotopic map for vapor over the SO. Variation of CO_2 concentration and the stable carbon isotopic composition can be expected from the present study as the growth rate of atmospheric CO_2 is continuously increasing. From physical data set the vertical profiles of temperature and salinity has been plotted at four stations, along 57°30'E meridional section at 35°31'S, 42°20'S, 47°40'S and 54°S to understand variability of temperature and salinity from different regions. Profiles were selected from subtropics, sub-Antarctic and Polar Regions. Profiles show the sea surface temperature reduces towards south. In subtropics thermocline is observed and vanishes in the south. Temperature gradually decreases in deeper layer in tropics whereas in polar region temperature remains almost constant below 400 m depth. The pycnocline layer in the top was observed in the polar region. The dissolved Oxygen, Nutrients, Trace metals, Total Organic Carbon, and $_{p}H$ measurements will reflect how chemical processes are regulating biogeochemical cycles in the SO. Based upon the isotopic composition of Nd (ε_{Nd}), various water masses would be identified from the vertical profiles of the water column as identified in North Atlantic Ocean. From biological point of view quantification, community composition and spatial distribution of phytoplankton would provide information on the structure and dynamics of marine ecosystem. Chlorophyll estimation would provide us information about phytoplankton presence through the different chlorophyll pigments and phaeopigments. The spatial distribution of diatoms in the sediments will be used as a valuable tool to infer the recent past climatic changes. An interesting observation includes the abundant presence of unidentified spindle shaped plankton in the Bongo net from 61°S latitude during onward track. In geological study the spatial distribution of foraminifera will be used for estimation of paleo-oceanography. Their isotopic composition will reveal the paleo–temperature and paleo–productivity. Grain size composition will reveal the transportation and provenance of sediment grains in the SO. The details results of the SO expedition are under process and analyses will be carries out in near future. Expedition was successful as all its scheduled tasks were accomplished.

Acknowledgments

The Chief Scientist and the participants are thankful to Dr. Shailesh Nayak, Secretary, Ministry of Earth Sciences (**MoES**), New Delhi for his constant encouragement and interest in the activities of this expedition. Thanks are also to Shri Rasik Ravindra, Director, NCAOR, Goa for his co-ordination and encouragement in successful completion of the expedition. Dr. M. Sudhakar, GD-OSSG, NCAOR helped us in planning and implementation of the expedition activities. We are particularly thankful to Capt. Vtorov Igor and his team of officer's onboard Akademik Boris Petrov for their excellent cooperation in carrying out different operations during this cruise and also for safely navigating the vessel in crucial times. NCAOR contract engineers provided a reasonably good maintenance, operation and trouble shooting of equipments onboard.

Annexure – I

Annexure - I

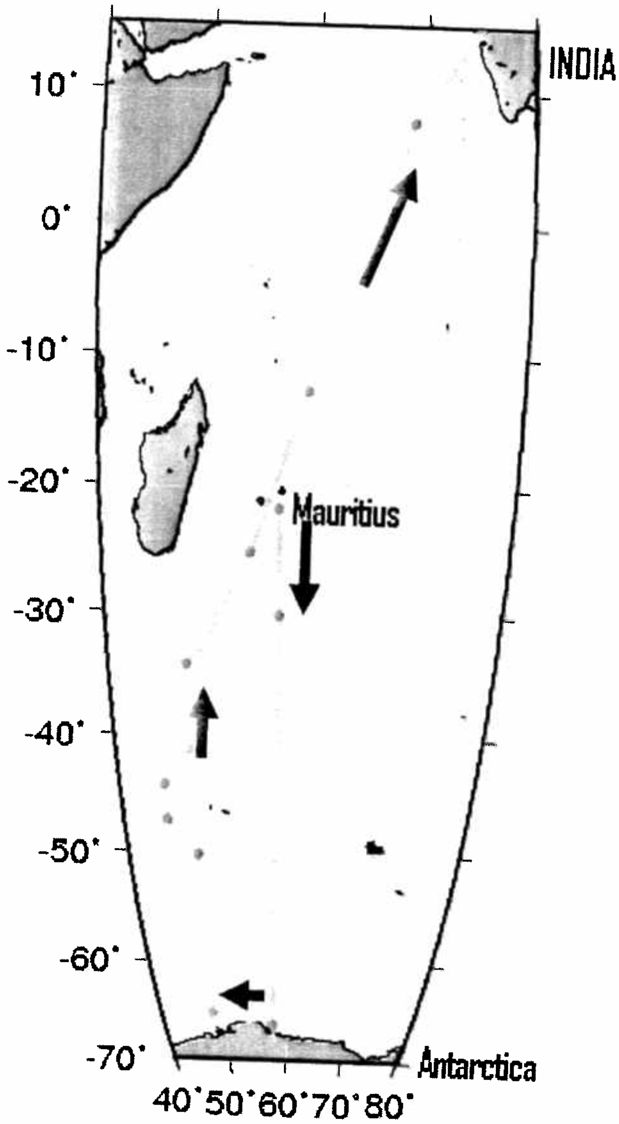

Figure 1: *Ship cruise track of Southern Ocean Expedition – 2009.*

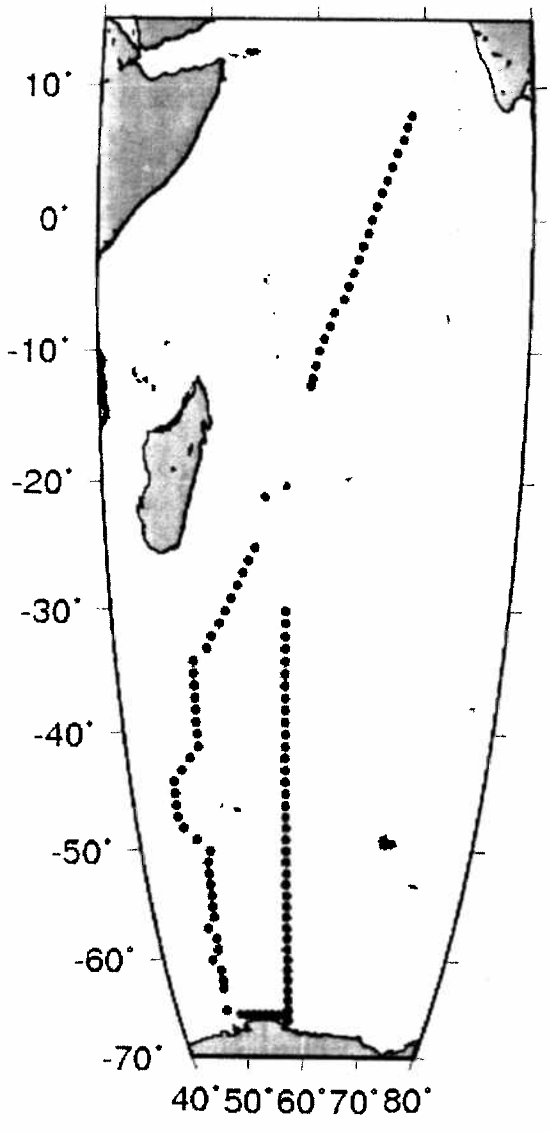

Figure 2: *Station location shows surface sea water (red symbol) sample collected during Southern Ocean Expedition 2009.*

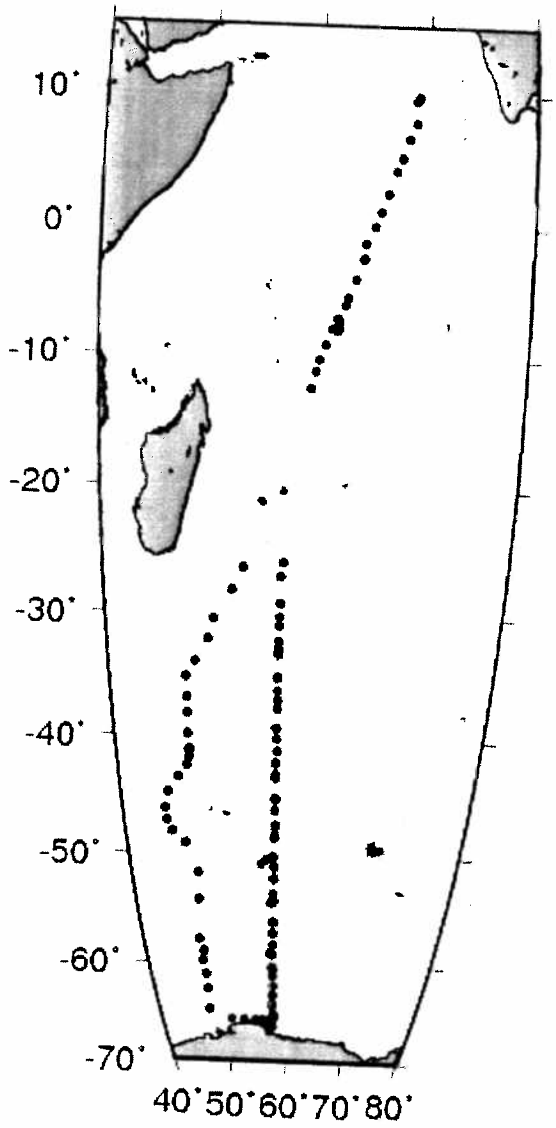

Figure 3: *Map shows the location of air (Blue solid circle) sample collected twice a day together with surface sea water and CO_2 (Red solid circle) sample collected during onward track in Southern Ocean Expedition 2009.*

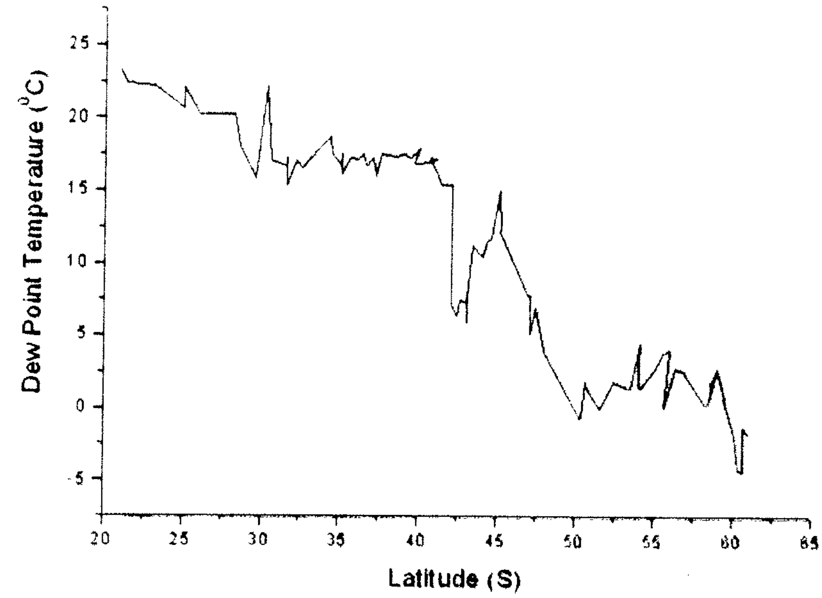

***Figure 4a**: Latitudinal variation of Dew point temperature along 57°30'E meridional section.*

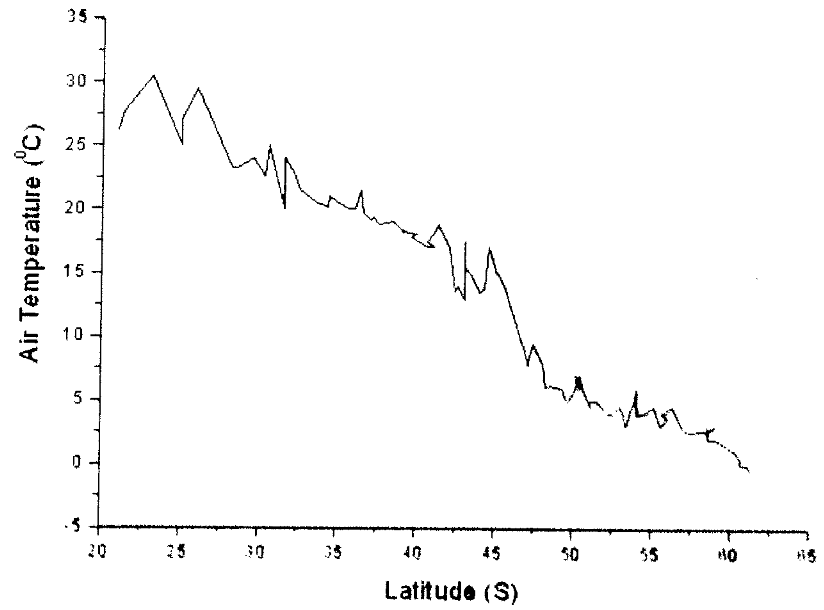

***Figure 4b**: Latitudinal variation of air temperature along 57°30'E meridional section.*

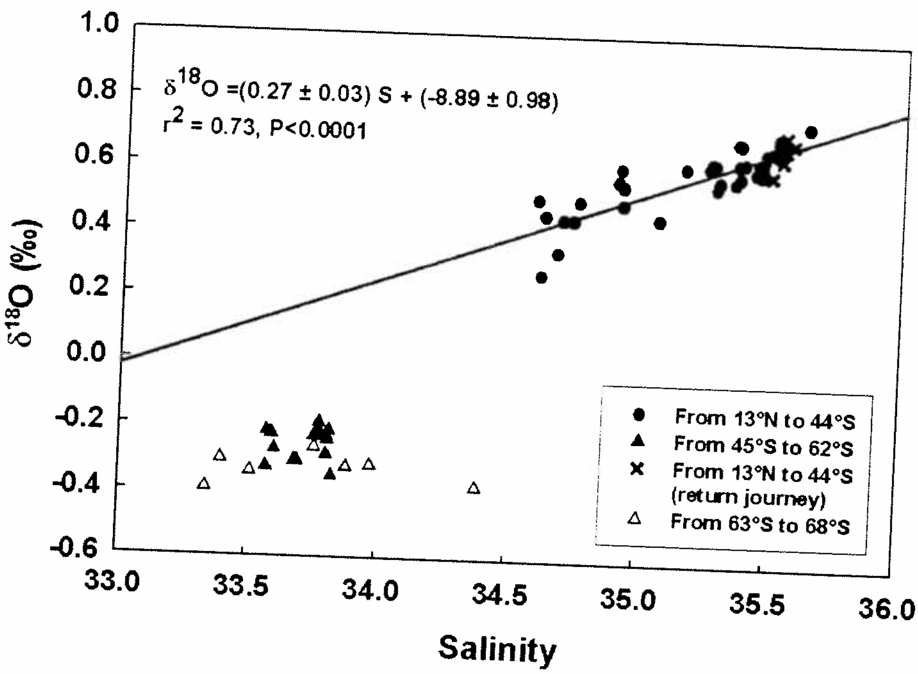

Figure 5: *$\delta^{18}O$ – salinity relationship for the Indian Ocean, 2006.*

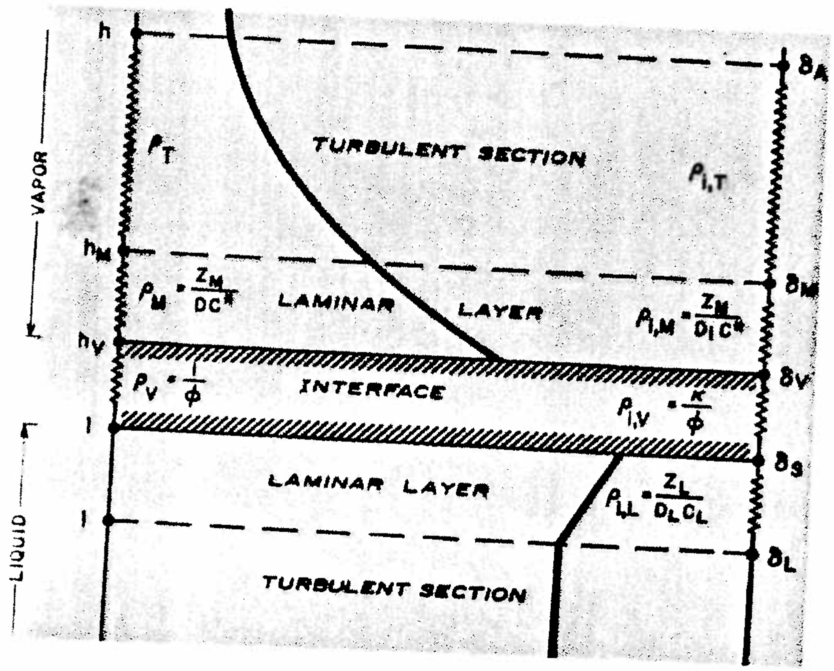

Figure 6: *A laminar layer model for an isolated liquid. The heavy curve in the vapor phase and liquid represents isotopic delta values for the vapor. The various ρ and ρ_i expressions are the transport resistance for the $H_2{}^{16}O$ and $H_2{}^{18}O$.*

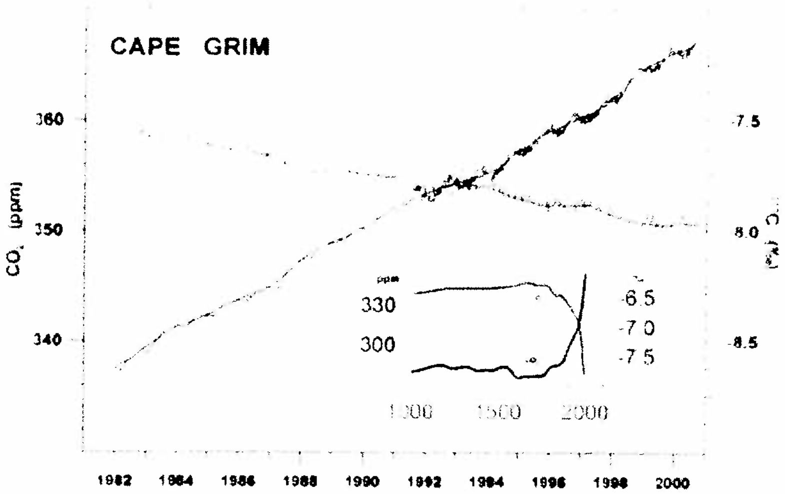

Figure 7: *The concentration and stable carbon isotopic composition variation in recent times from Cape Grim (Source NOAA).*

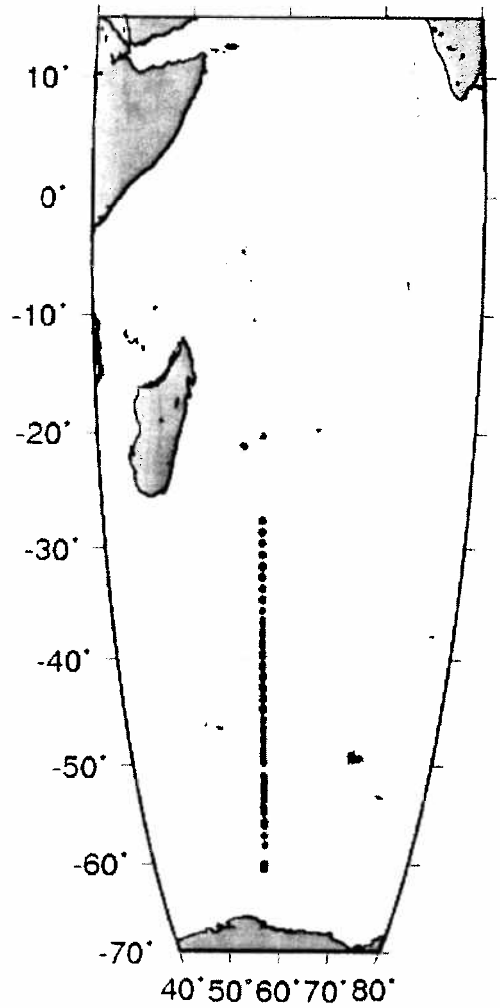

Figure 8: *Map shows the location XBT (Blue solid circle) and XCTD (Red solid circle) operation along ship track.*

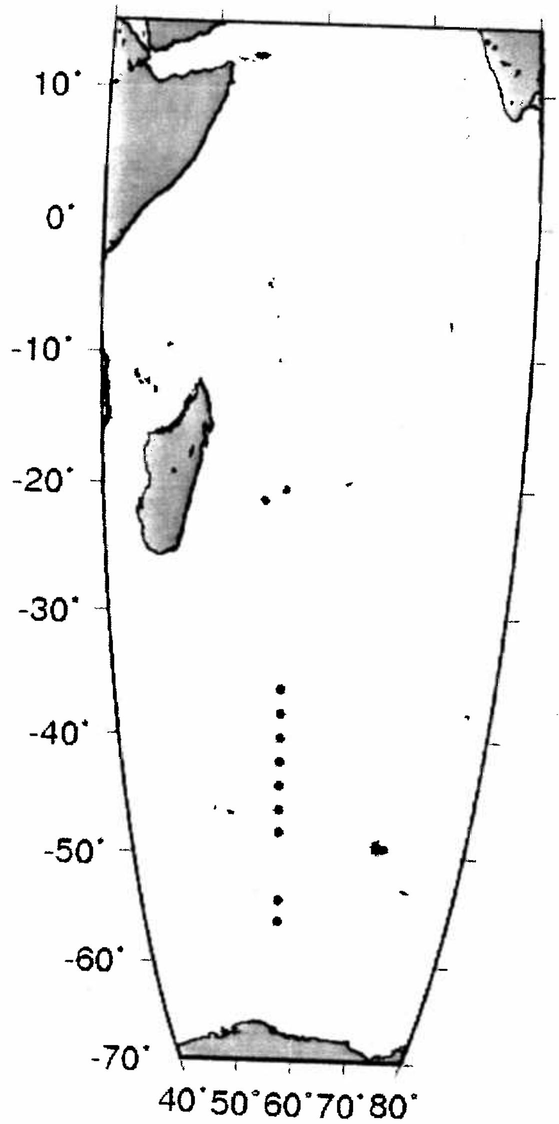

***Figure 9:** Map shows the location of portable CTD operation during Southern Ocean Expedition - 2009.*

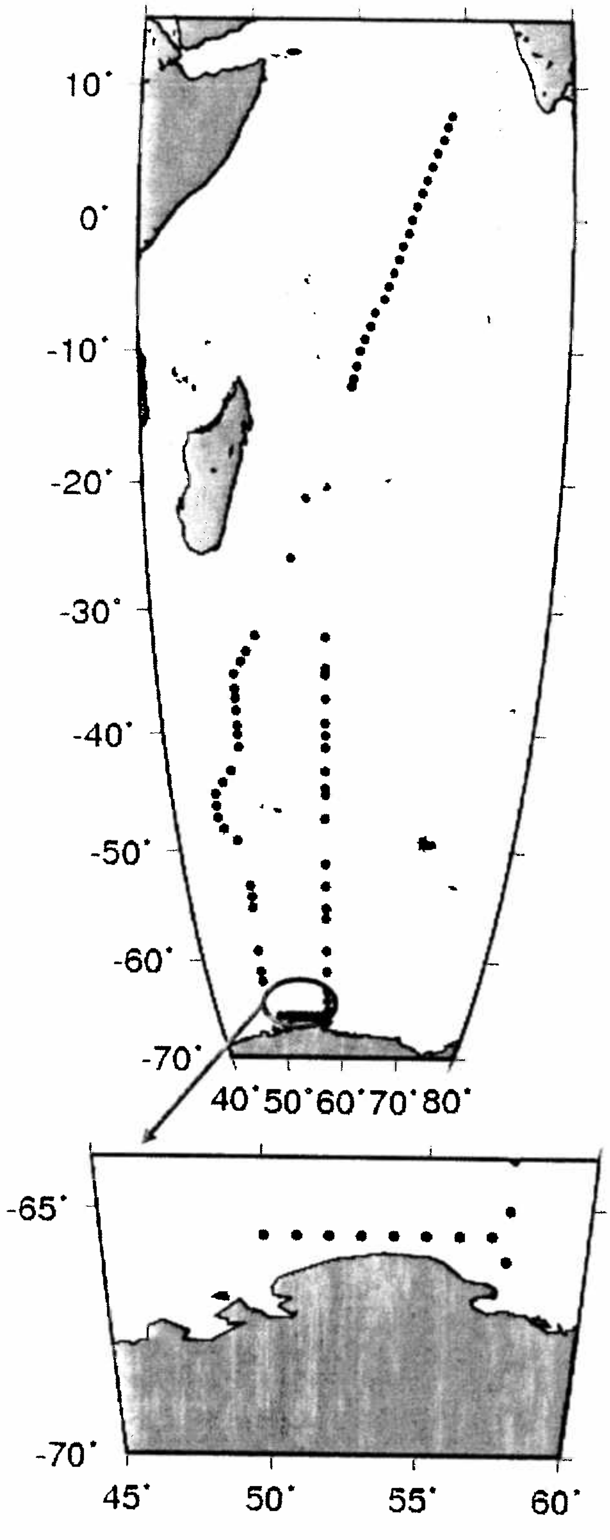

Figure 10: *Map shows the location of CTD operation during Southern Ocean Expedition - 2009.*

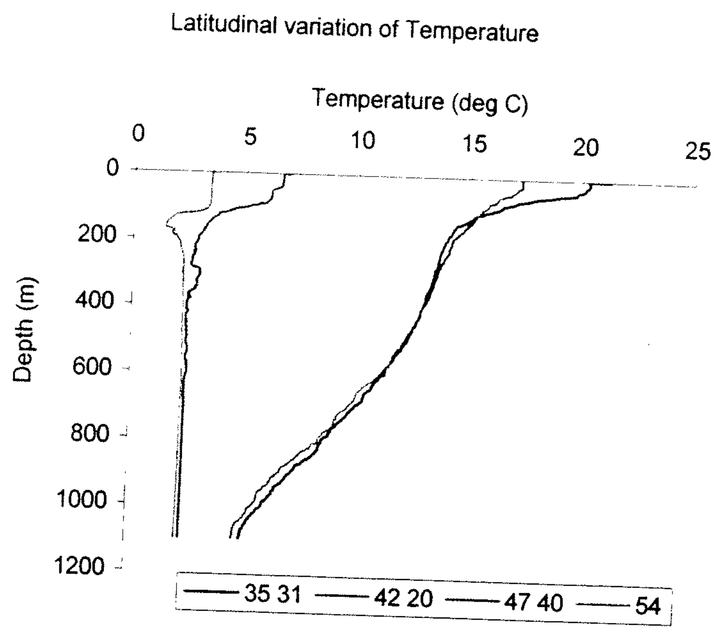

Figure 11a: Latitudinal variation of temperature along 57°30'E cruise track at selected stations (35°31'S, 42°20'S, 47°40'S, 54°S) using XCTD.

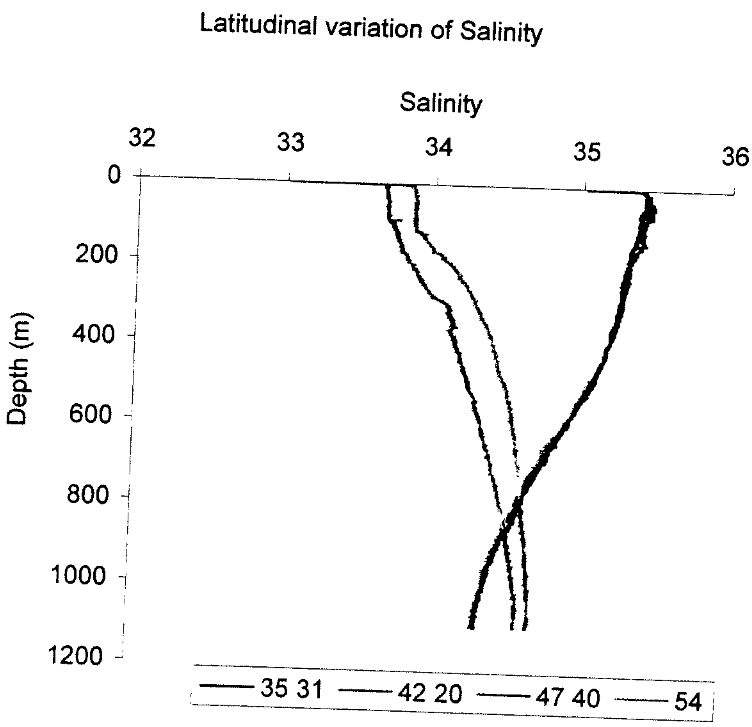

Figure 11b: Latitudinal variation of salinity along 57°30'E cruise track at selected stations (35°31'S, 42°20'S, 47°40'S, 54°S) using XCTD.

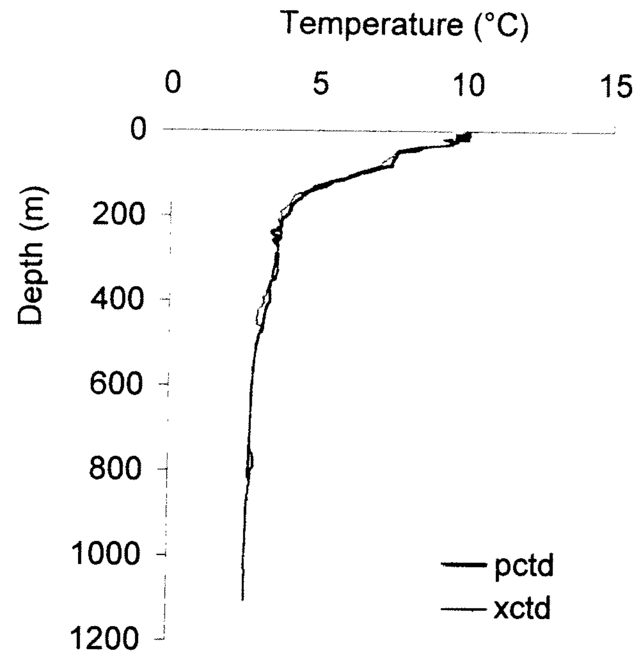

Figure 12a: *Comparative profile of temperature using pCTD and XCTD at 46°S.*

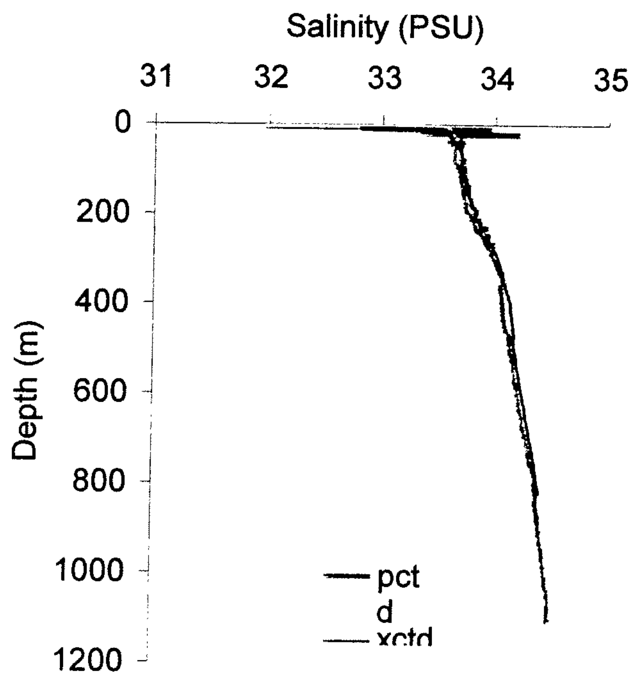

Figure 12b: *Comparative profile of salinity using pCTD and XCTD at 46°S.*

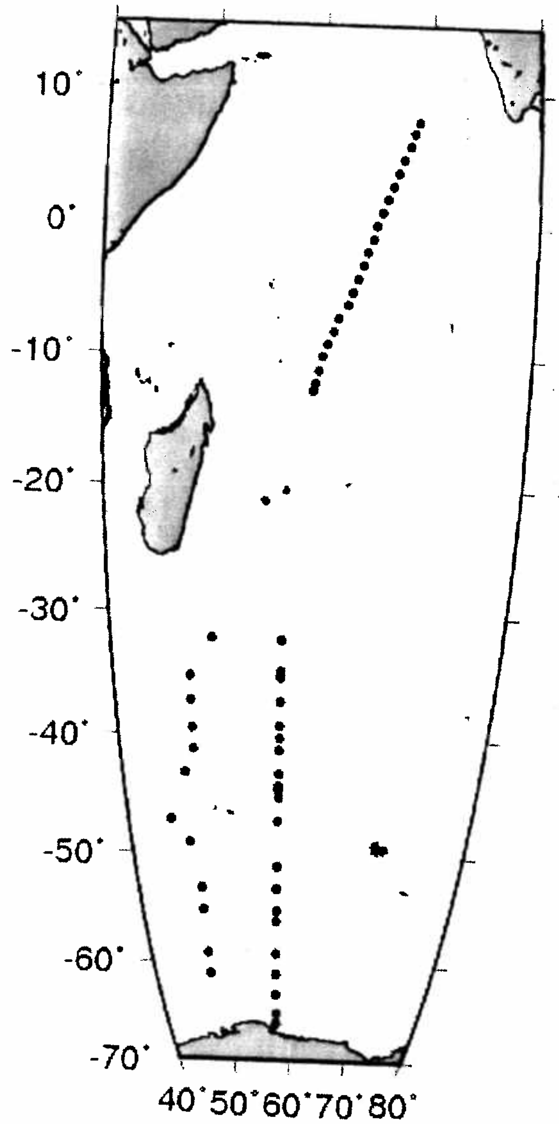

Figure 13: *Station location shows Sea water sample collected using CTD Rosette sampler at different depth levels.*

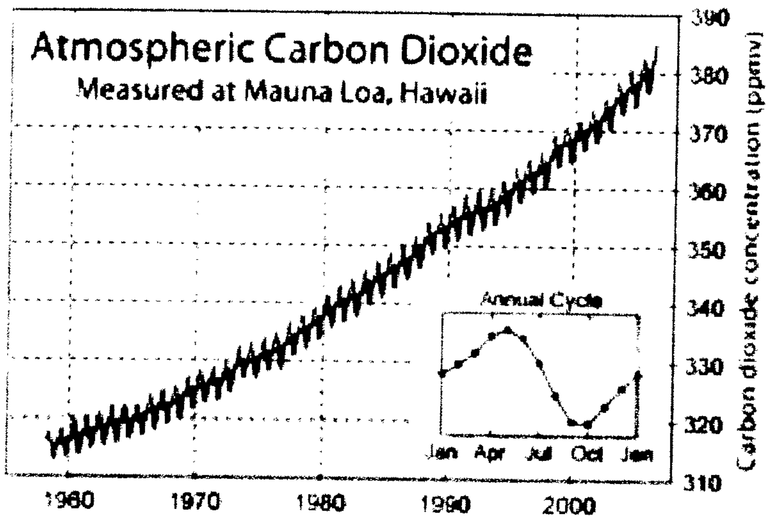

Figure 14: *Profile of atmospheric carbon dioxide shows increased tremendously in last few decades.*

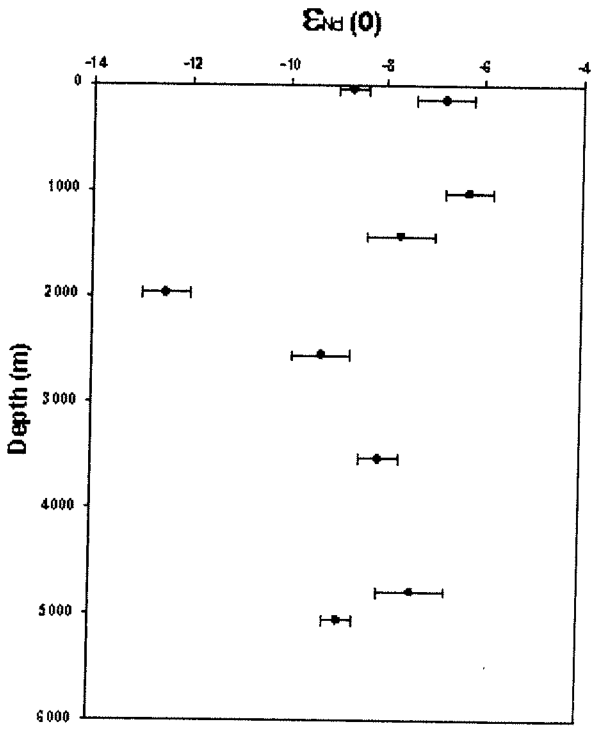

Figure 15: *. Isotopic composition of Nd (ε_{Nd}) in the Southern Atlantic.*

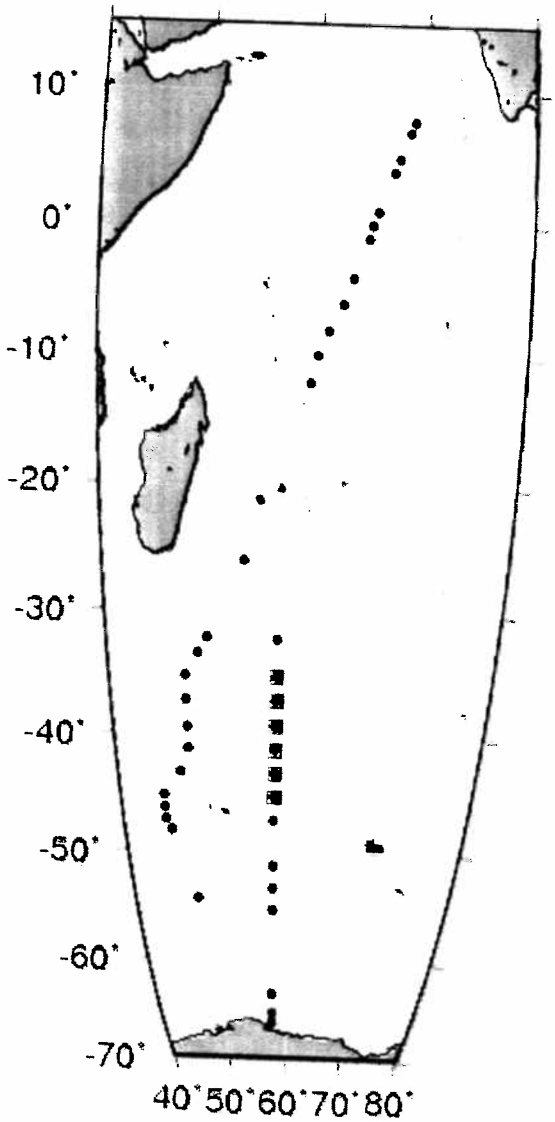

Figure 16: *Station location shows Bongo net (Blue solid circle) operations for collection of surface phytoplankton and zooplankton sample and Multi-Plankton Net operation in top 200m water column (Pink square box).*

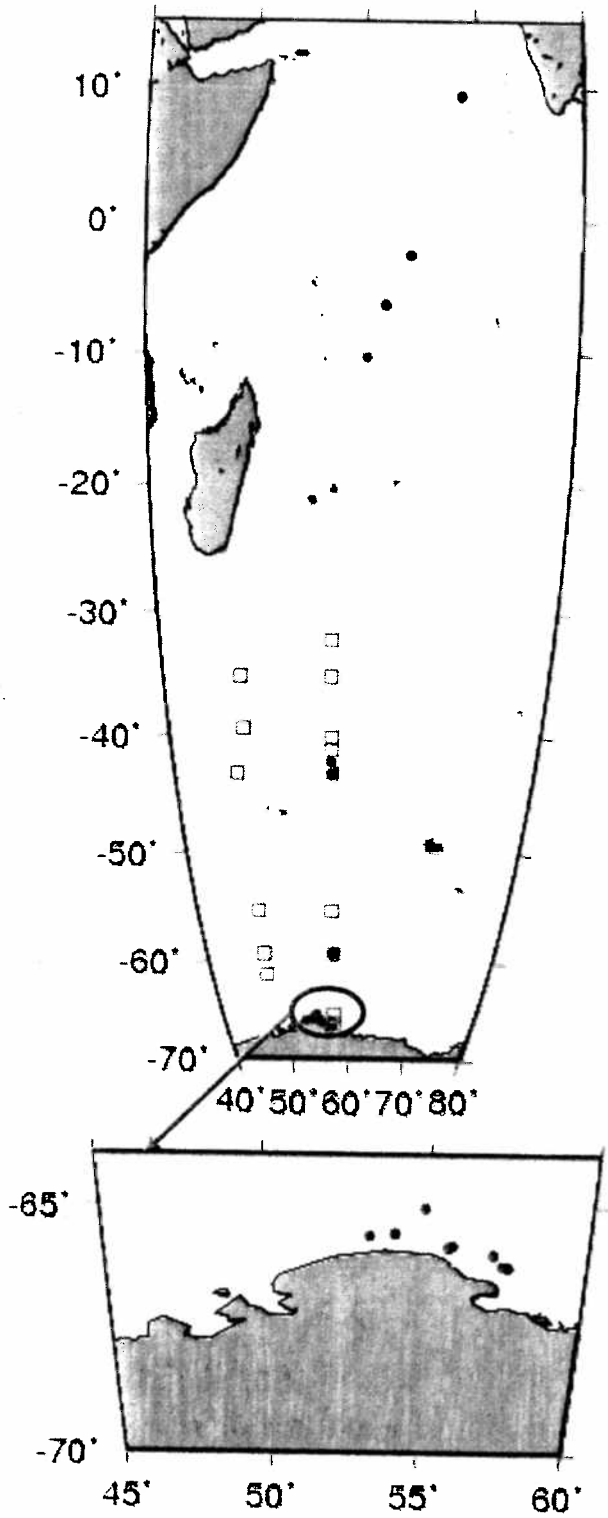

***Figure 17:** Station location shows Gravity corer (Blue solid circle) and Van Veen Grab (Red solid circle) operations along ship track. Subsurface sea water sampling at selected location is shown in Green square box.*

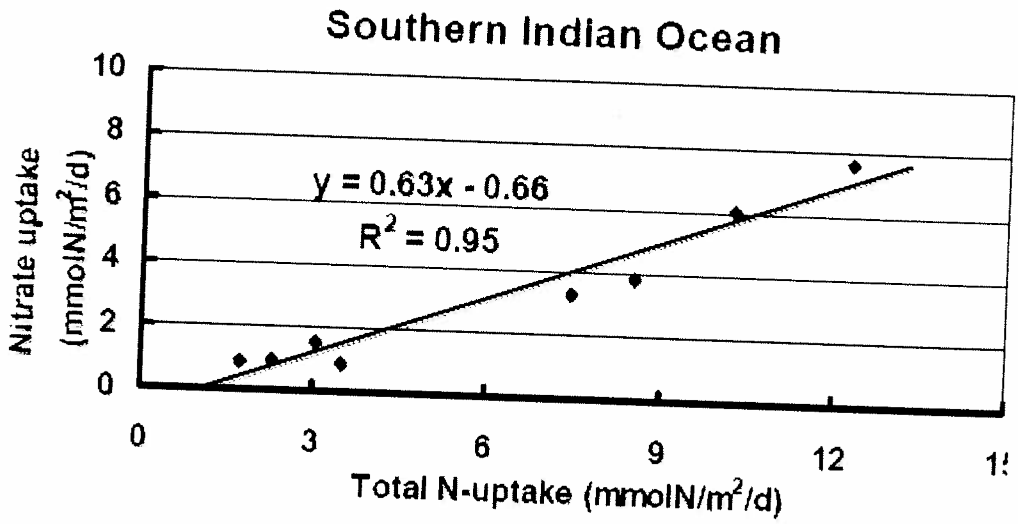

Figure 18: *Relationship between measured total N uptake and nitrate uptake in the Southern Indian Ocean obtain during 2006.*

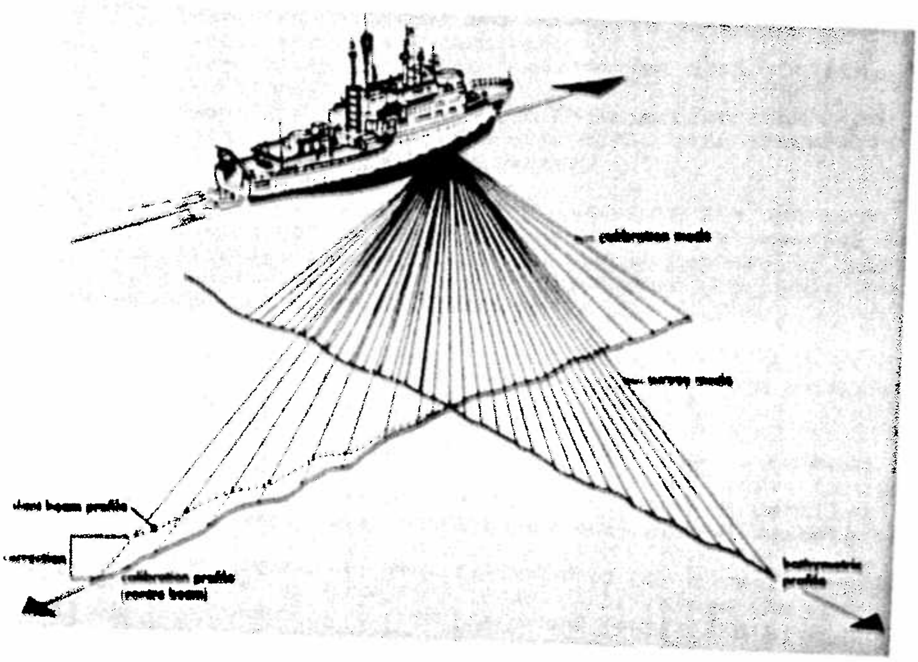

Figure 19: *Calibration procedure of Atlas Hydrosweep used in survey.*

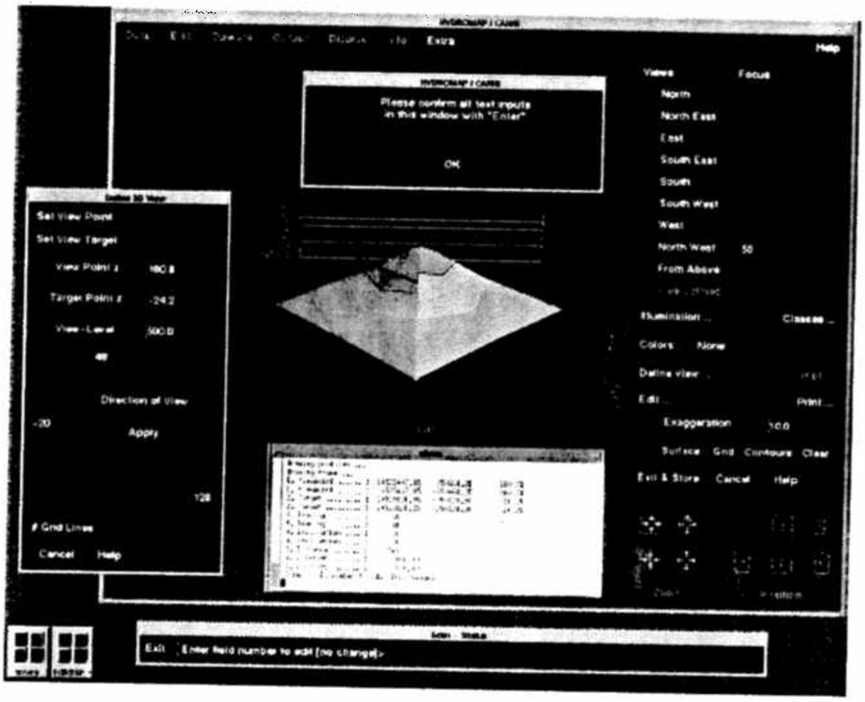

Figure 20: *Graphical user interface with different windows and icons (example: CARIS).*

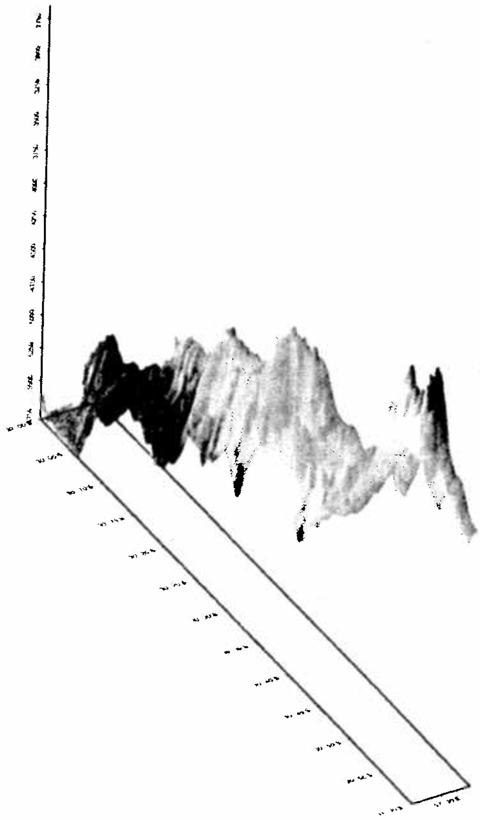

Figure 21: *Hydrosweep swath between 30°S to 31°S along 57°30'E meridional section (3D view).*

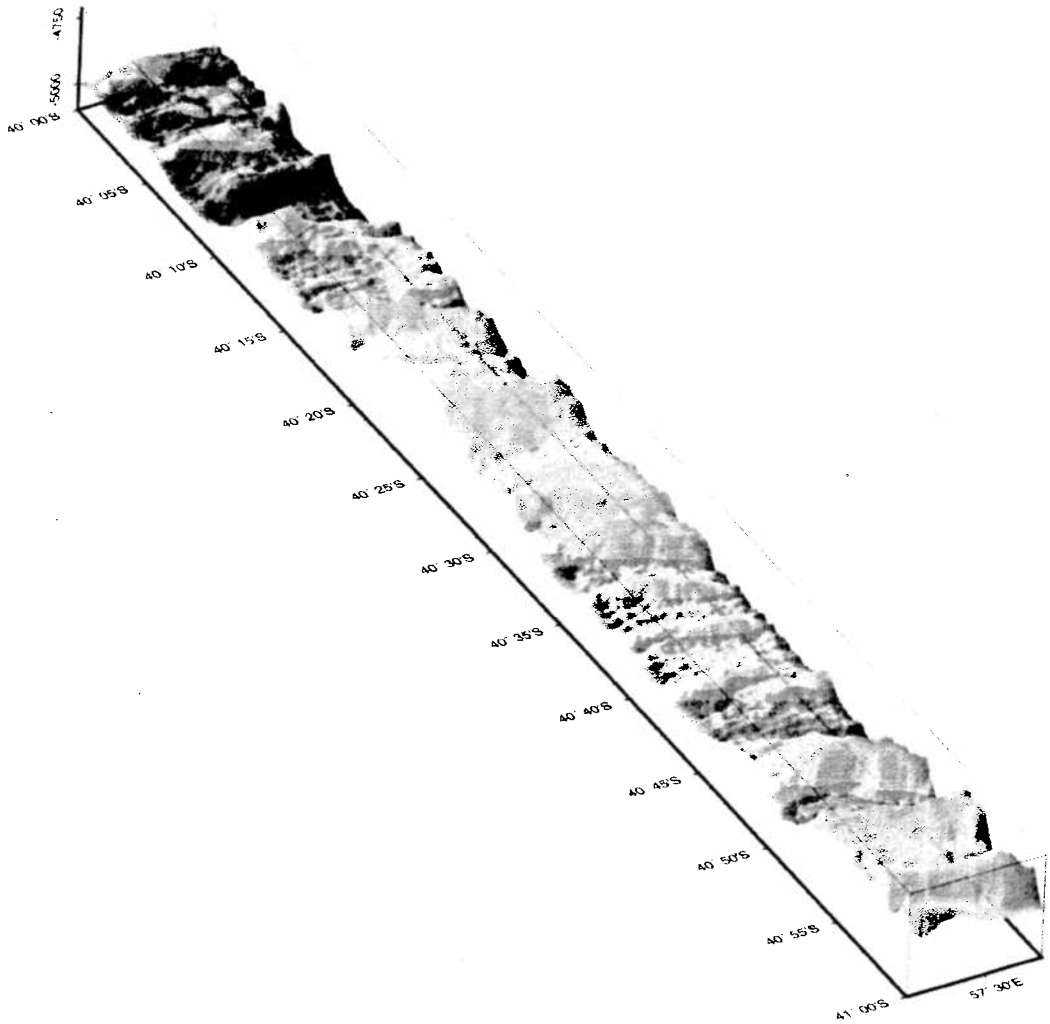

Figure 22: *Hydrosweep swath between 40°S to 41°S along 57°30'E meridional section (3D view).*

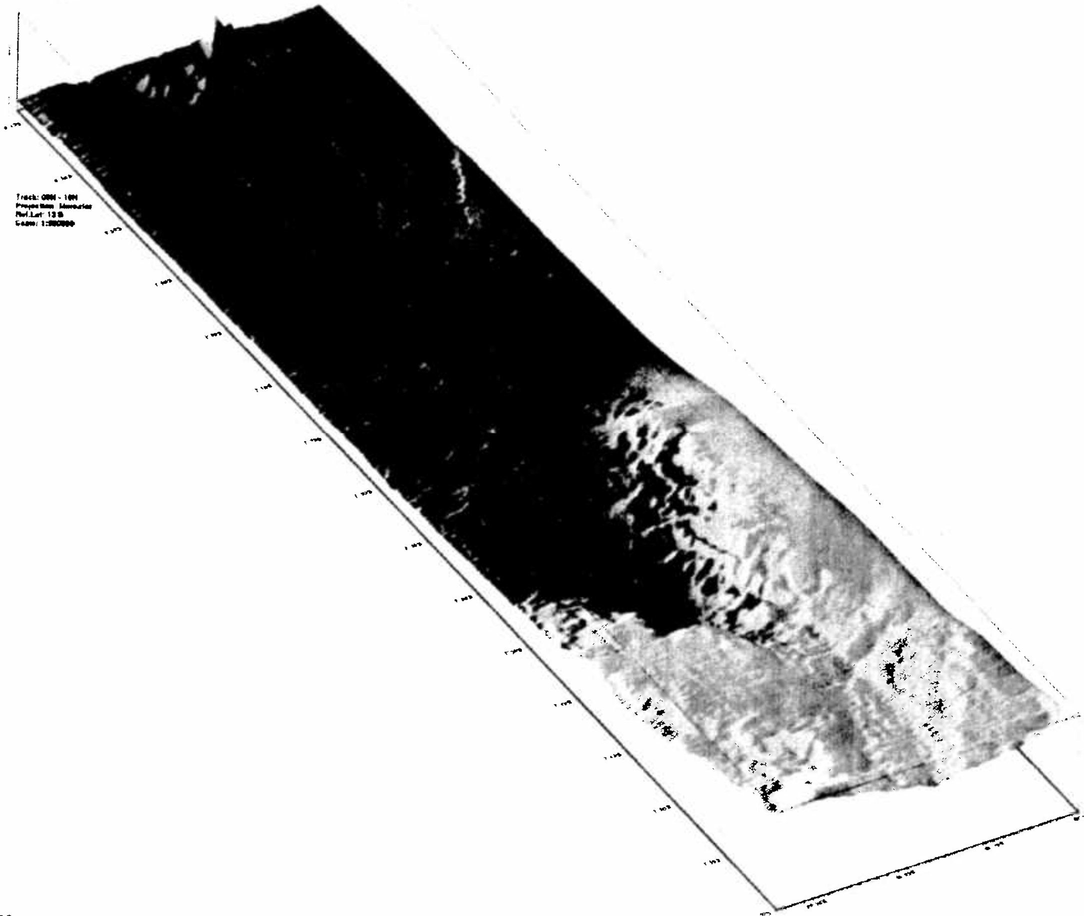

Figure 23: *Hydrosweep bathymetric swath survey during return journey from Mauritius to India (Goa) (3D view).*

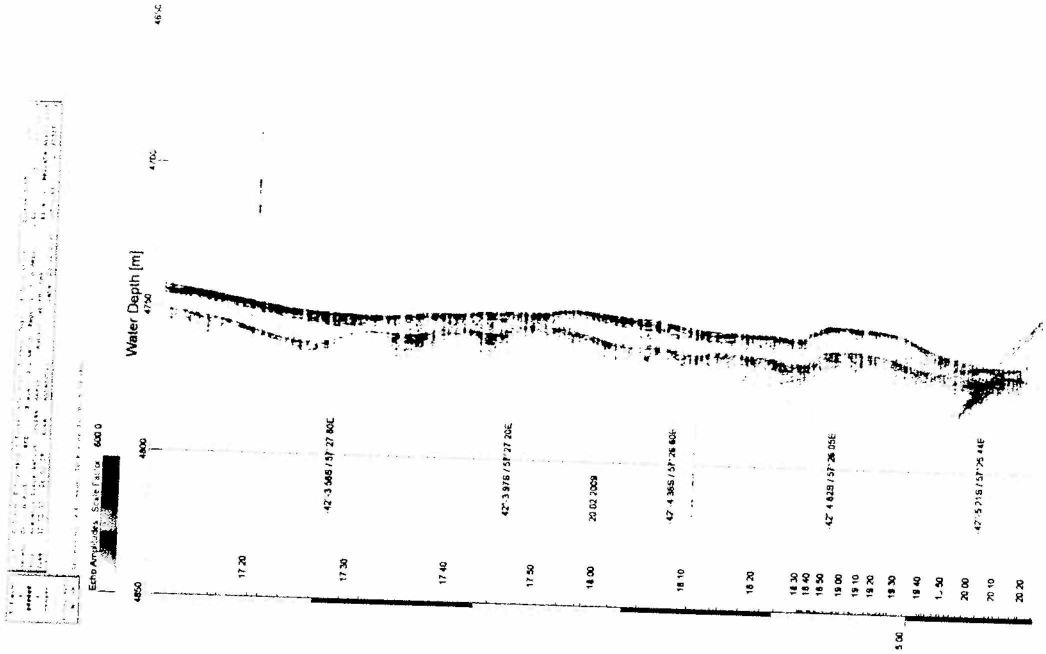

Figure 24: *Parasound sub bottom profiler during Gravity corer operation at position 42°S, 57°30'E.*

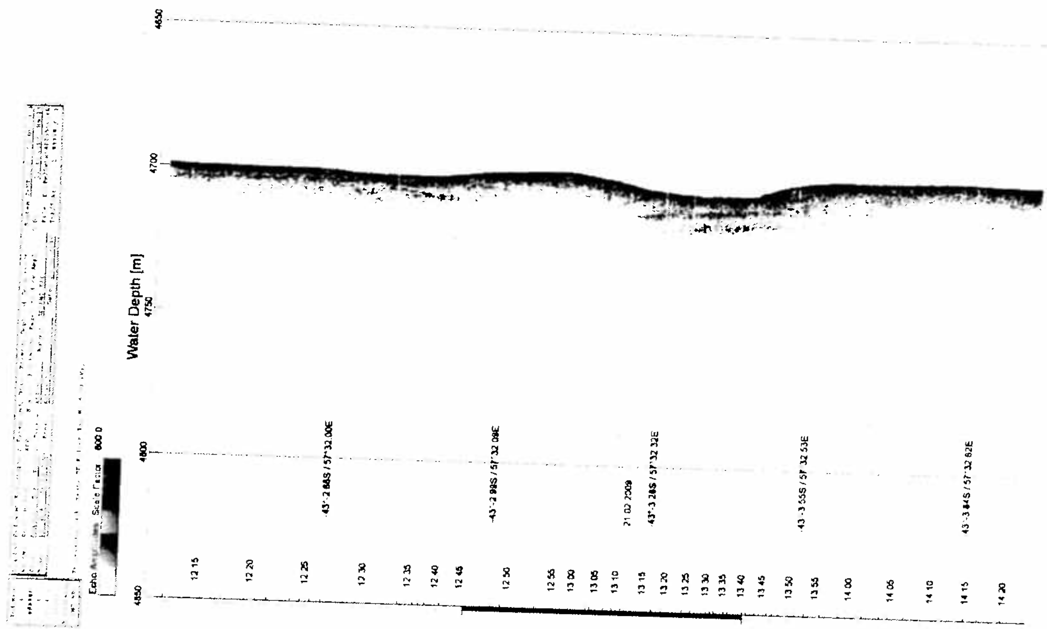

Figure 25: *Parasound sub bottom profiler during Gravity corer operation at position 43°S, 57°30'E.*

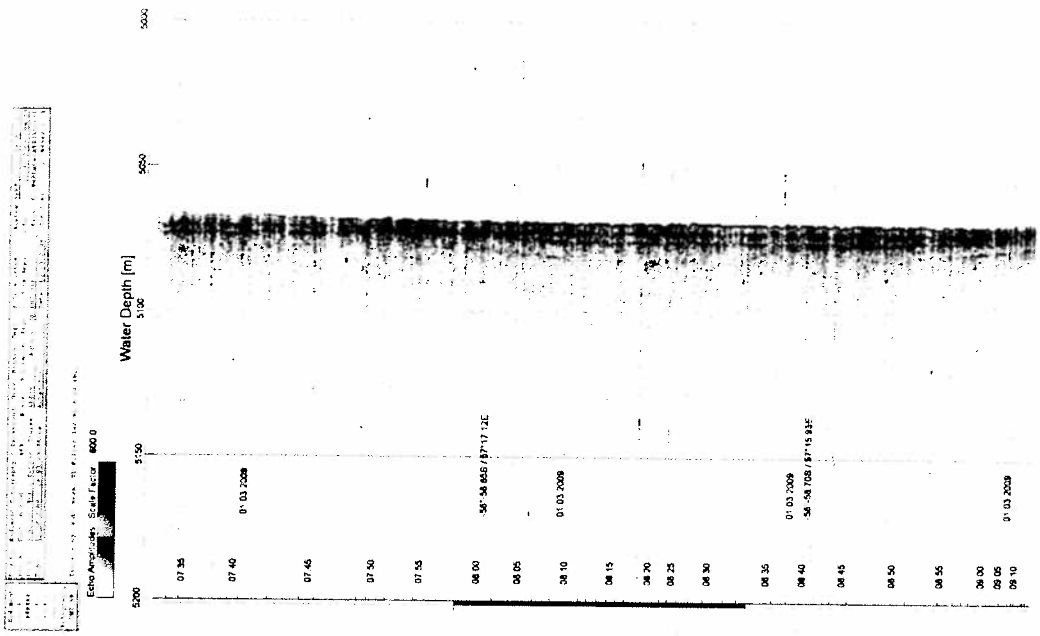

Figure 26: Parasound sub bottom profiler during Gravity corer operation at position 59°S, 57°30'E.

Annexure - II

Annexure - II

Plate 01: Scientific team of Southern Ocean Expedition - 2009.

Plate 02: Picture shows the kinks on 18 mm deep sea winch cable due to looping and entangling of wire rope around AFM.

Plate 03: Picture shows damaged Niskin and Goflo bottles due to hitting of CTD frame at the side wall of the ship during rough weather.

Plate 04: Picture shows the assembly of Automatic Weather Station (AWS). The left panel show radiation sensor and right panel show assembly of anemometer, wind vane, humidity sensor and air temperature sensor.

Plate 05: Picture shows the atmospheric water vapor collection unit. Left panel shows before adding liquid Nitrogen gas and right panel shows after adding liquid Nitrogen gas in jars.

Plate 06: Pictures shows the CTD unit with Carousal sampler ready for operation in left panel and sea water collection in right panel.

Plate 07: Pictures show the procedure of adding reagents to the sea water sample to do further analyses at laboratory.

Plate 08: Pictures show the procedure involved to keep sea water sample collected for trace element and Nd measurements.

Plate 09: Pictures show the equipment for filtering sea water sample collected for further analyses.

Plate 10: Picture shows the procedure to filter water sample for Diatoms.

Plate 11: Pictures show the sample collection, tracer addition and filtration onboard.

Plate 12: Pictures show the operation of Multi-Plankton Net (MPN) onboard.

Plate 13: Pictures show the operation of Bongo net dragged with 2 knot ship speed (left panel) and sample collection shown in right panel.

Plate 14: Picture shows the photographs of organism (Jelly fish) obtained using Bongo net.

Plate 15: Picture shows filtration unit for suspended materials.

Plate 16: Picture shows equipments used to collect deep sea sediment with Gravity corer (left panel) and surface sediment sampler with grab sampler (right panel).

Plate 17: Pictures shows the photographs of organism obtained using grab sampler in left panel (Sea lilly) and right panel (Brittle star).

Plate 1: *Scientific team of Southern Ocean Expedition - 2009.*

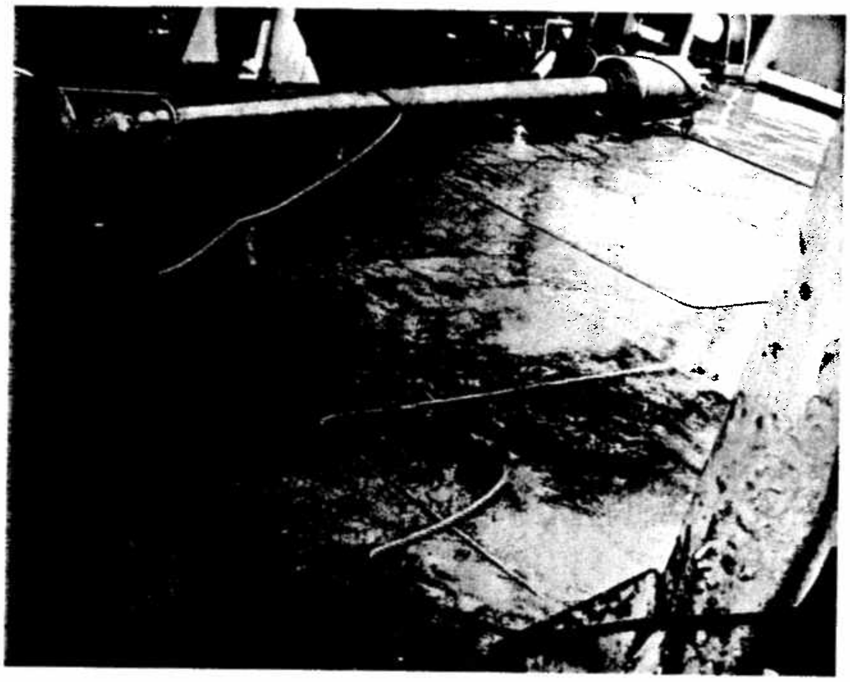

Plate 2: *Picture shows the kinks on 18 mm deep sea winch cable due to looping and entangling of wire rope around AFM.*

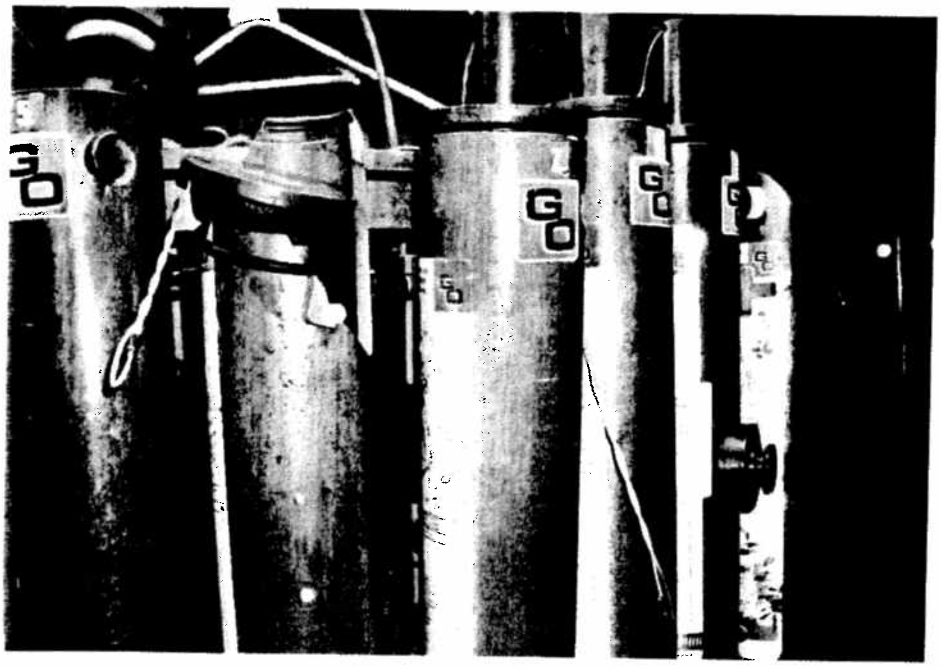

Plate 3: *Picture shows damaged Niskin and Goflo bottles due to hitting CTD frame at the side wall of the ship during rough weather.*

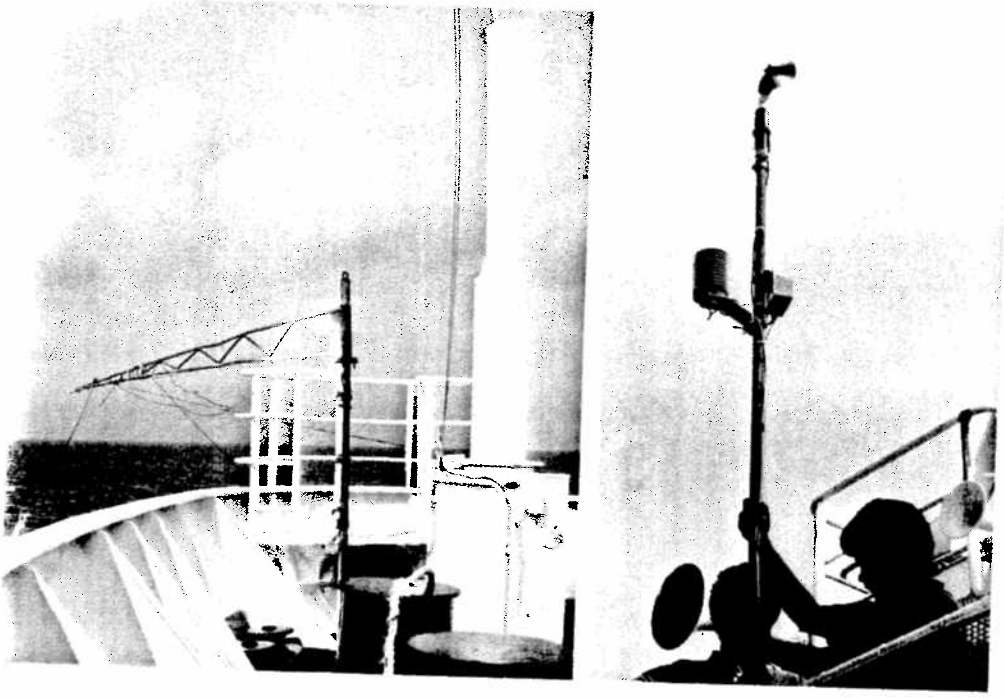

Plate 4: *Picture shows the assembly of Automatic Weather Station (AWS). The left panel show radiation sensor and right panel show assembly of anemometer, wind vane, humidity sensor and air temperature sensor.*

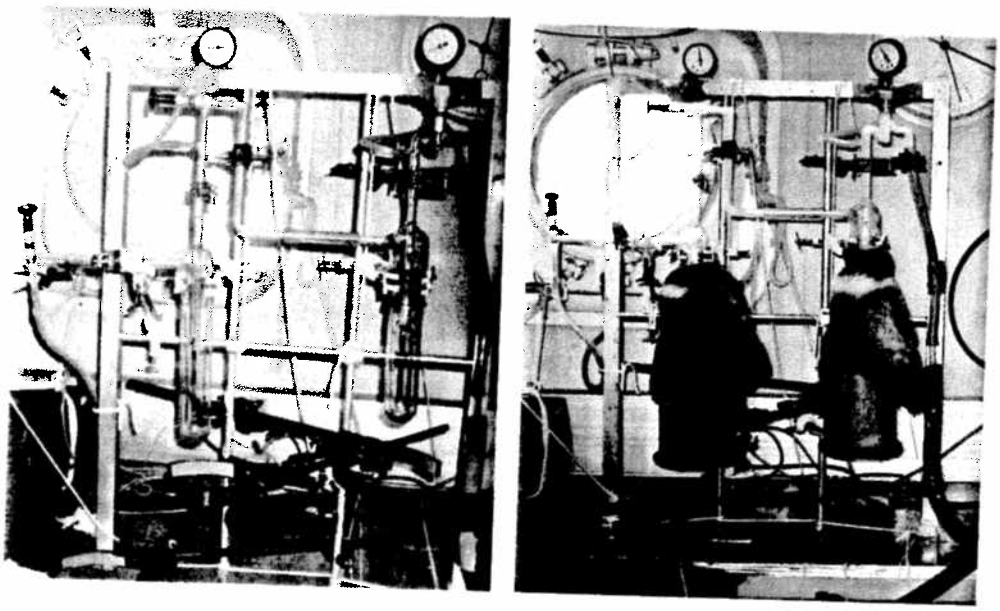

Plate 5: *Picture shows the atmospheric water vapor collection unit. Left panel shows before adding liquid Nitrogen gas and right panel shows after adding liquid Nitrogen gas in jars.*

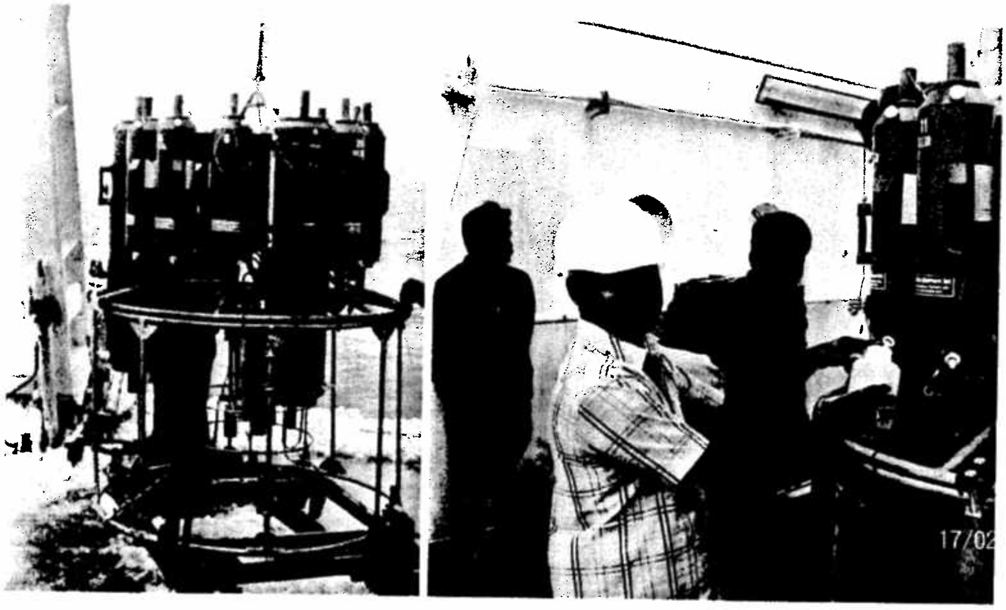

Plate 6: *Pictures show the CTD unit with carousal sampler ready for operation in left panel and sea water collection in right panel.*

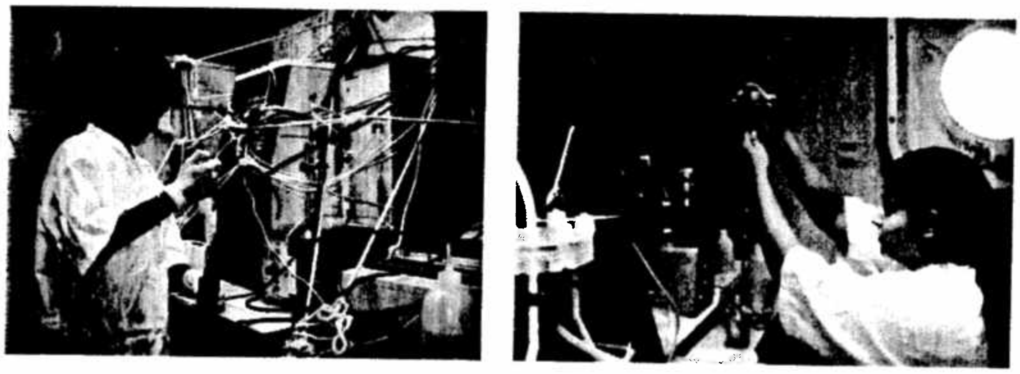

Plate 7: *Pictures show the procedure of adding reagents to the sea water sample to do further analyses at laboratory.*

Plate 8: *Pictures show the procedure involved to keep sea water sample collected for trace element and Nd measurements.*

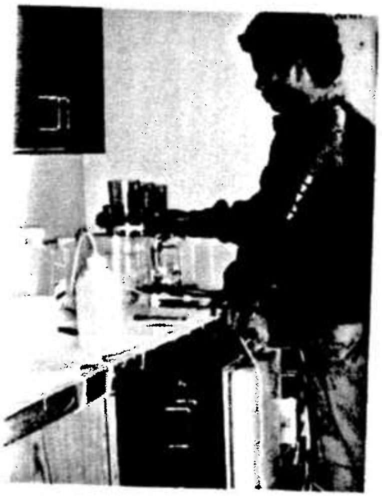


Plate 9: *Pictures show the equipment for filtering sea water sample collected for further analyses.*

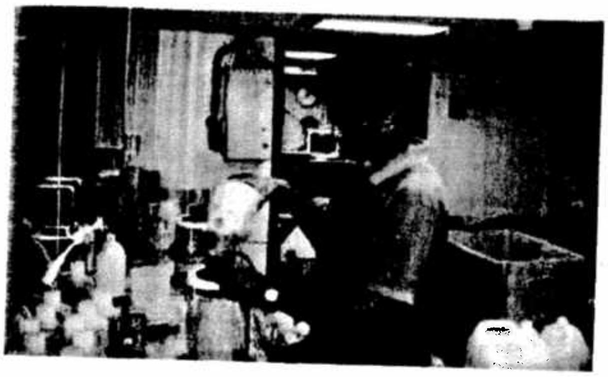

Plate 10: *Picture shows the procedure to filter water sample for Diatoms.*



Plate 11: *Pictures show the sample collection, tracer addition and filtration onboard.*

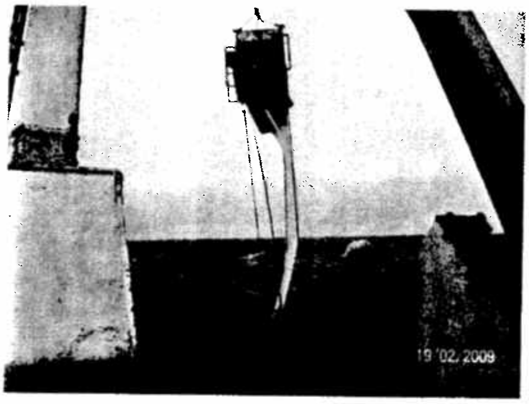

Plate 12: *Pictures show the operation of Multi-Plankton Net (MPN) onboard.*

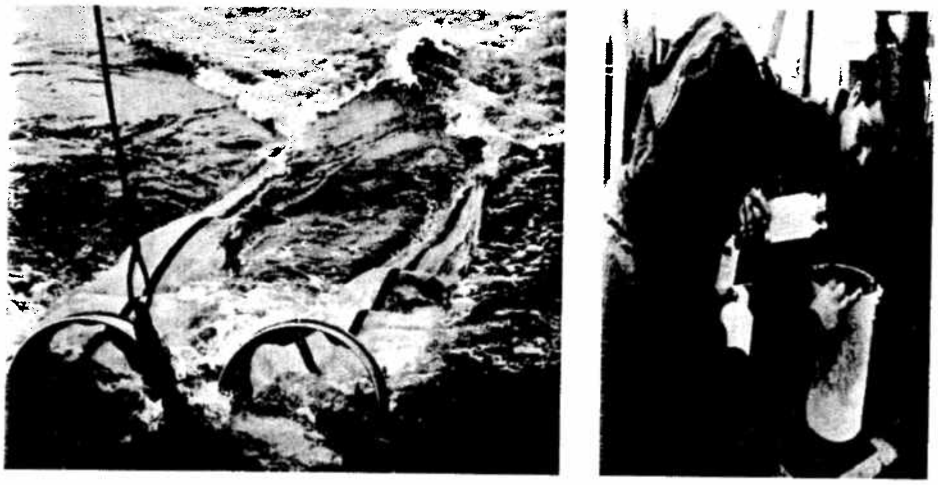

Plate 13: *Pictures show the operation of Bongo net dragged with 2 knot ship speed (left panel) and sample collection shown in right panel.*

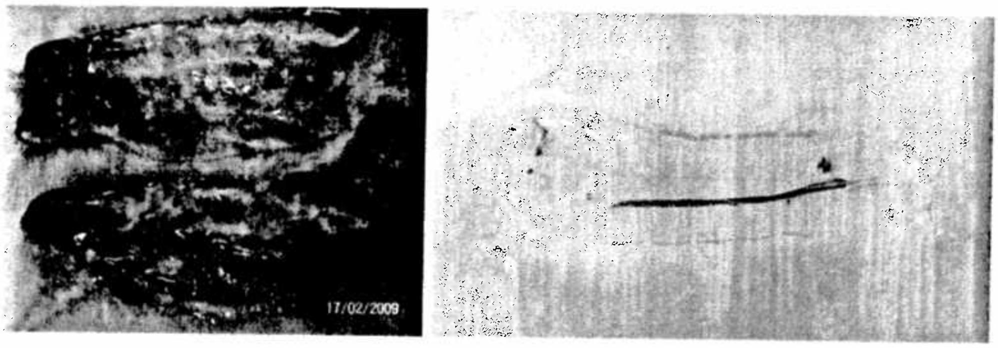

Plate 14: *Picture shows the photographs of organism (Jelly fish) obtained using Bongo net.*

Plate 15: *Picture shows filtration unit for suspended materials.*

Plate 16: *Picture shows equipments used to collect deep sea sediment with Gravity corer (left panel) and surface sediment sampler with Grabe sampler (right panel).*

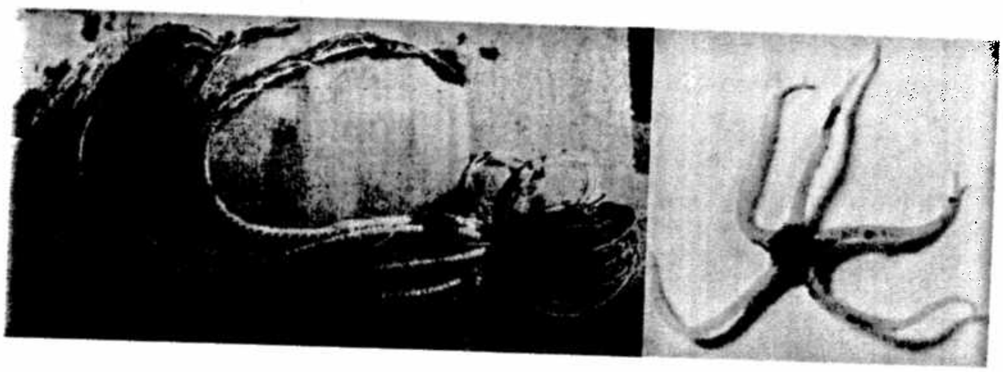

Plate 17: *Pictures shows the photographs of organism obtained using grab sampler in left panel (Sea lilly) and right panel (Brittle star).*

Annexure – III

Annexure – III

Table-01: Show the positions of surface sea water sample collected in one degree interval and atmospheric water vapour collected twice a day at 1030 hrs and 2030 hrs during **(a)** onward track, **(b)** & **(c)** returned track by PRL

Table-02: Show the positions of sea water samples collected at different depths levels using niskin during **(a)** onward track, **(b)** & **(c)** returned track by PRL.

Table-03: Rain samples were collected to verify Rayleigh isotopic fractionation over oceans by PRL.

Table-04: Two snow samples and one ice sample (surface frozen ice) collected during onward journey by PRL.

Table-05: Discrete air samples have been collected to study the growth rate of -atmospheric CO2, in 1 litre glass bottles by PRL.

Table-06: Shows the station position of XBT operations during onward cruise track by NCAOR.

Table-07: Shows the station position of XCTD operations during onward cruise track by NCAOR.

Table-08: Shows the station position of portable CTD operations during onward cruise track by NCAOR.

Table-09: Shows the station position of CTD operations during onward cruise track by NCAOR.

Table-10: Shows the station position of CTD operations during across cruise track by NCAOR.

Table-11: Shows the station position of CTD operations during returned cruise track by NCAOR.

Table-12: Shows the station position of CTD operations from Mauritius to India (Goa) returned cruise track by NCAOR.

Table-13: Shows the stations location for study of Chemical parameters during **(a)** onward track, **(b)** & **(c)** returned track by NCAOR.

Table-14: Shows the time series observation for study of Chemical parameters in Antarctic coastal waters by NCAOR.

Table-15: Shows the samples collected for trace element and Nd measurement at the following depths: 5 m, 50 m, 100 m, 200 m, 300 m, 400 m, 500 m, 600 m, 700 m, 800 m, 900 m and 1000 m during **(a)** onward track **(b) & (c)** returned track. For Neodymium, samples from sea surface were collected at an interval of every two degrees by PRL

Table-16: Shows the stations location for study of Biological parameters during **(a)** onward track, **(b) & (c)** returned track by NCAOR.

Table-17: Time series observations for the study of Biological parameters (phytoplankton) in Antarctic coastal waters by NCAOR.

Table-18: Samples collected for nanophosphor application **(a)** onward track, **(b) & (c)** returned track by KBCAOS.

Table-19: Samples collected for total productivity using couple tracer technique **(a)** onward track, **(b) & (c)** returned track by PRL.

Table-20: Samples collected for analyses of DO-Dissolved Oxygen, PP(UF)- Phytoplankton unfiltered, PP(F) Phytoplankton filtered, MZP- microzooplankton, MeZP- mesozooplankton, S- Surface during **(a)** onward track, **(b) & (c)** returned track by CMLRE.

Table-21: Shows the grab sample collected for macrobenthic and meiobenthic studies by CMLRE.

Table-22: Shows details of the Bongo operations in the SO for zooplankton studies during **(a)** onward track, **(b) & (c)** returned track by NCAOR, CMLRE and Karnataka University.

Table-23: Sea water sample collection at selected depth level using rosette during **(a)** onward track, and **(b)** returned track by Goa University.

Table-24: Shows the details of the sediment samples collected using gravity corer by NCAOR.

Table-25: Shows the details of the surface sediment samples collected using grab sampler by NCAOR, CMLRE, Goa University and KBCAOS.

Table-26: Shows the details of the sea surface water sample collected by Goa University.

Table-27: Shows the details of the 5 unidentified illuminations recorded between Mauritius and Southern Ocean by Karnataka University.

Table-01a

Station Number	Date	Latitude (°S)	Longitude (°E)
1	14/02/09	26.9	57.5
2	15/02/09	29.0	57.5
3	15/02/09	30.8	57.5
4	16/02/09	32.0	57.5
5	16/02/09	32.6	57.5
6	17/02/09	34.9	57.5
7	17/02/09	35.0	57.4
8	18/02/09	36.8	57.5
9	18/02/09	37.5	57.5
10	19/02/09	39.1	57.5
11	19/02/09	40.0	57.5
12	20/02/09	41.0	57.6
13	20/02/09	42.0	57.5
14	21/02/09	43.0	57.5
15	21/02/09	43.2	57.5
16	22/02/09	45.0	57.5
17	22/02/09	46.0	57.5
18	23/02/09	47.3	57.6
19	23/02/09	48.4	57.5
20	24/02/09	50.1	57.4
21	24/02/09	50.3	56.6
22	25/02/09	50.7	55.9
23	25/02/09	51.0	57.6
24	26/02/09	52.0	57.5
25	26/02/09	53.4	57.5
26	27/02/09	54.0	57.5
27	27/02/09	54.2	57.4
28	28/02/09	56.0	57.5
29	28/02/09	57.0	57.5
30	01/03/09	59.0	57.4
31	01/03/09	58.9	57.1
32	02/03/09	60.5	57.5
33	02/03/09	61.1	57.5
34	03/03/09	63.0	57.5
35	03/03/09	64.0	57.5
36	04/03/09	65.0	57.5
37	04/03/09	65.2	57.7
38	05/03/09	66.2	57.5
39	05/03/09	65.7	57.0
40	06/03/09	65.5	55.9
41	06/03/09	65.5	55.0
42	07/03/09	65.5	53.1
43	07/03/09	65.5	51.0

Table-01b

Station Number	Date	Latitude (°S)	Longitude (°E)
44	08/03/09	64.5	47.8
45	09/03/09	62.5	48.0
46	09/03/09	61.0	48.0

47	10/03/09	59.7	47.8
48	10/03/09	58.8	48.1
49	11/03/09	57.7	47.6
50	13/03/09	54.0	48.0
51	14/03/09	51.6	48.2
52	15/03/09	49.0	47.0
53	15/03/09	48.0	45.6
54	16/03/09	47.0	45.0
55	16/03/09	46.0	45.0
56	17/03/09	44.6	45.4
57	17/03/09	43.3	46.7
58	18/03/09	42.3	47.7
59	18/03/09	41.6	48.0
60	19/03/09	41.0	48.1
61	19/03/09	41.0	48.0
62	20/03/09	41.0	48.0
63	20/03/09	39.7	48.0
64	21/03/09	38.0	48.0
65	21/03/09	36.7	48.0
66	22/03/09	3 5.0	48.0
67	22/03/09	33.7	49.0
68	23/03/09	31.9	50.3
69	23/03/09	30.3	50.9
70	24/03/09	28.0	52.7
71	24/03/09	26.2	53.8

Table-01c

Station Number	Date	Latitude	Longitude (E)
72	31/03/09	12.3 S	59.8
73	31/03/09	11.0 S	60.2
74	01/04/09	10.1 S	60.5
75	01/04/09	09.0 S	61.0
76	02/04/09	07.8 S	61.5
77	02/04/09	07.0 S	62.0
78	03/04/09	07.0 S	62.1
79	03/04/09	07.9 S	62.1
80	04/04/09	07.2 S	62.2
81	04/04/09	07.7 S	62.2
82	05/04/09	07.5 S	62.1
83	05/04/09	06.0 S	62.7
84	06/04/09	05.4 S	62.9
85	06/04/09	04.0 S	63.6
86	07/04/09	02.4 S	64.3
87	07/04/09	02.5 S	64.3
88	08/04/09	01.3 S	64.4
89	08/04/09	00.0 S	65.2
90	09/04/09	01.1 N	65.7
91	09/04/09	02.5 N	66.3
92	10/04/09	04.2 N	67.0
93	10/04/09	05.2 N	67.5
94	11/04/09	06.6 N	68.1

95	11/04/09	07.8 N	68.7
96	12/04/09	09.5 N	68.7
97	12/04/09	09.8 N	68.9

Table-02a

Station Number	Date	Latitude (S)	Longitude (E)
1	17/02/09	31.0	57.5
2	20/02/09	41.0	57.5
3	25/02/09	51.0	57.6
4	04/03/09	65.0	57.5

Table-02b

Station Number	Date	Latitude (S)	Longitude (E)
5	13/03/09	55 00	48 00
6	15/03/09	49 00	47 00
7	17/03/09	44 00	46 00
8	20/03/09	41 00	48 00
9	21/03/09	38 00	48 00
10	22/03/09	35 00	48 00
11	24/03/09	25 47	54 00

Table-02c

Station Number	Date	Latitude (S)	Longitude (E)
1	31/03/09	12 00	59 54
2	01/04/09	09 54	60 30
3	06/04/09	05 00	63 07
4	08/04/09	00 00	65 08
5	10/04/09	05 00	67 24

Table-03

Station Number	Date	Latitude (S)	Longitude (E)
1	19/02/09	39.0	57.5
2	19/02/09	39.0	57.5
3	19/02/09	39.1	57.5
4	19/02/09	39.1	57.5
5	19/02/09	40.0	57.5

Table-04

Station Number	Date	Latitude (S)	Longitude (E)
1	04/03/09	64.6	57.5
2	07/03/09	65.5	53.1
3	06/03/09	65.8	55.6

Table-05

Sl. No.	Date	Latitude (S)	Longitude (E)	Experiment performed
1	14/02/09	25° 46'	57° 46'	Air CO_2 sample collected
2	15/02/09	30° 05'	57°29'	Air CO_2 sample collected
3	17/02/09	33° 06'	57° 30'	Air CO_2 sample collected
4	18/02/09	36° 00'	57° 29'	Air CO_2 sample collected
5	19/02/09	39° 05'	57° 29'	Air CO_2 sample collected
6	20/02/09	42° 02'	57° 30'	Air CO_2 sample collected
7	22/02/09	45° 06'	57° 37'	Air CO_2 sample collected
8	23/02/09	48° 01'	57° 32'	Air CO_2 sample collected
9	24/02/09	50° 03'	57° 25'	Air CO_2 sample collected
10	26/02/09	52° 00'	57° 30'	Air CO_2 sample collected
11	27/02/09	54° 11'	56° 57'	Air CO_2 sample collected
12	28/02/09	56° 01'	57° 30'	Air CO_2 sample collected
13	01/03/09	58° 06'	57° 30'	Air CO_2 sample collected
14	02/03/09	60° 14'	57° 27'	Air CO_2 sample collected
15	03/03/09	62° 07'	57° 30'	Air CO_2 sample collected
16	03/03/09	63° 59'	57° 29'	Air CO_2 sample collected
17	05/03/09	65° 56'	57° 07'	Air CO_2 sample collected

Table-06

XBT Operations					
Sr. No.	Date	Time	Latitude (S)	Longitude (E)	Profile Depth
1	15/02/09	0000	27 29	57 30	760
2	15/02/09	0830	28 30	57 30	760
3	15/02/09	1432	29 30	57 29	760
4	15/02/09	2030	30 30	57 29	760
5	16/02/09	0349	31 30	57 30	760
6	16/02/09	2130	32 30	57 30	760
7	17/02/09	0300	33 30	57 30	760
8	17/02/09	0830	34 30	57 30	760
9	02/03/09	0800	60 00	57 26	760
10	02/03/09	1100	60 31	57 21	760

Table-07

XCTD Operations					
Sr. No.	Date	Time	Latitude (S)	Longitude (E)	Profile Depth
1	18/02/09	0230	35 31	57 30	1100
2	18/02/09	1015	36 20	57 30	1100
3	18/02/09	1150	36 40	57 30	1100
4	18/02/09	2030	37 20	57 30	1100
5	18/02/09	2230	37 40	57 30	1100
6	19/02/09	0348	38 21	57 30	1100
7	19/02/09	0530	38 40	57 30	1100
8	19/02/09	1600	39 20	57 30	1100
9	19/02/09	1800	39 40	57 30	1100
10	20/02/09	0126	40 20	57 30	1100
11	20/02/09	0252	40 40	57 30	1100
12	20/02/09	1618	41 20	57 35	1100
13	20/02/09	1810	41 40	57 30	1100

14	21/02/09	0405	42 20	57 26	1100
15	21/02/09	0640	42 40	57 30	1100
16	21/02/09	2209	43 20	57 30	1100
17	22/02/09	0005	43 40	57 30	1100
18	22/02/09	0720	44 20	57 30	1100
19	22/02/09	1020	44 40	57 30	1100
20	22/02/09	1745	45 30	57 33	1100
21	22/02/09	1933	45 40	57 32	1100
22	23/02/09	0140	46 20	57 29	1100
23	23/02/09	0320	46 40	57 30	1100
24	23/02/09	1230	47 20	57 34	1100
25	23/02/09	1448	47 40	57 31	1100
26	23/02/09	2050	48 20	57 29	1100
27	23/02/09	2250	48 40	57 29	1100
28	24/02/09	0147	49 00	57 31	1100
29	24/02/09	0451	49 20	57 30	1100
30	24/02/09	0708	49 40	57 30	1100
31	25/02/09	1935	51 00	57 30	1100
32	26/02/09	0504	51 23	57 39	1100
33	26/02/09	0657	51 40	57 36	1100
34	26/02/09	0945	52 00	57 30	1100
35	26/02/09	1130	52 20	57 30	1100
36	26/02/09	1330	52 40	57 30	1100
37	26/02/09	2015	53 20	57 34	1100
38	27/02/09	1611	54 00	57 25	1100
39	27/02/09	2130	54 20	57 26	1100
40	27/02/09	2300	54 40	57 29	1100
41	28/02/09	0640	55 30	57 34	1100
42	28/02/09	1430	56 00	57 33	1100
43	28/02/09	2100	57 00	57 30	1100
44	01/03/09	0215	58 00	57 30	1100
45	02/03/09	0800	60 00	57 26	1100

Table-08

Portable CTD operations along Meridional section 57°30'E					
Sr. No.	**Date**	**Time**	**Latitude (S)**	**Longitude (E)**	**Profile Depth**
1	18/02/09	06.30	36 00	57 30	1000
2	19/02/09	00.15	38 00	57 30	1000
3	19/02/09	20.00	40 00	57 30	1000
4	20/02/09	20.40	42 00	57 30	1000
5	22/02/09	04.00	44 00	57 30	1000
6	22/02/09	21.45	46 00	57 30	1000
7	23/02/09	04.30	48 00	57 30	1000
8	27/02/09	12.10	54 00	57 30	4600
9	28/02/09	10.30	56 00	57 30	3500

Table-09

CTD Operations along Meridional section 57°30'E					
Sr. No.	**Date**	**Time**	**Latitude (S)**	**Longitude (E)**	**Profile Depth m**
1	16/02/09	1035	32 00	57 30	1000
2	17/02/09	0825	34 30	57 30	0095

3	17/02/09	1320	35 00	57 30	1000
4	17/02/09	1400	37 00	57 30	1000
5	19/02/09	0834	39 00	57 30	1000
6	20/02/09	0541	41 00	57 30	1000
7	21/02/09	1035	43 00	57 30	1000
8	22/02/09	0830	44 26	57 30	1000
9	22/02/09	1215	45 00	57 30	1000
10	23/02/09	0658	47 00	57 30	1000
11	25/02/09	1845	51 00	57 30	1000
12	26/02/09	1540	53 00	57 30	1000
13	27/02/09	1200	54 00	57 30	2500
14	28/02/09	0115	55 00	57 30	1000
15	28/02/09	0945	56 00	57 30	0075
16	01/03/09	1128	59 00	57 30	1000
17	02/03/09	1535	61 00	57 30	1000
18	03/03/09	0927	63 00	57 30	1000
19	03/03/09	2022	64 00	57 30	1000
20	04/03/09	0644	65 00	57 30	1000
21	05/03/09	0721	66 00	57 30	0800

Table-10

CTD Operations along Zonal section 65°30'S					
Sr, No.	**Date**	**Time**	**Latitude (S)**	**Longitude (E)**	**Profile Depth**
1	05/03/09	2230	65 30	57 00	1000
2	06/03/09	0838	65 30	56 00	1000
3	06/03/09	1655	65 30	55 00	0650
4	07/03/09	0000	65 30	54 00	1000
5	07/03/09	0947	65 30	53 10	0500
6	07/03/09	1610	65 30	52 00	1000
7	07/03/09	2050	65 30	51 00	1000
8	08/03/09	0045	65 30	50 00	1000

Table-11

CTD Operations along Meridional section 48°E					
Sr. No.	**Date**	**Time**	**Latitude (S)**	**Longitude (E)**	**Profile Depth**
1	09/03/09	1538	62 00	48 00	1000
2	09/03/09	2340	61 00	48 00	1000
3	10/03/09	1820	59 00	48 00	1000
4	12/03/09	0020	55 00	48 00	1000
5	13/03/09	0950	54 00	48 00	1000
6	13/03/09	1735	53 00	48 00	1000
7	15/03/09	0840	49 00	47 00	1000
8	15/03/09	1834	48 00	45 35	1000
9	16/03/09	1147	47 00	45 00	1000
10	16/03/09	2127	46 00	45 00	1000
11	17/03/09	0634	45 00	45 00	1000
12	17/03/09	1512	44 00	46 00	1000
13	17/03/09	0155	43 00	47 00	1000
14	20/03/09	0817	41 00	48 00	1000
15	20/03/09	1735	40 00	48 00	1000
16	20/03/09	2355	39 13	48 00	1000
17	21/03/09	0917	38 00	48 00	1000

18	21/03/09	1640	37 00	48 00	1000
19	21/03/09	2352	36 13	48 00	1000
20	22/03/09	0824	35 00	48 00	1000
21	22/03/09	1720	34 00	48 45	1000
22	22/03/09	2330	33 10	49 22	1000
23	23/03/09	0815	31 53	50 19	1000
24	25/03/09	2300	25 47	54 02	1000

Table-12

CTD Operations from Mauritius to India (Goa)					
Sr. No.	**Date**	**Time**	**Latitude (S)**	**Longitude (E)**	**Profile Depth**
1	31/03/09	0900	12 33	59 44	1000
2	31/03/09	1300	12 00	59 54	1000
3	31/03/09	1945	11 00	60 12	1000
4	01/04/09	1300	09 54	60 30	1000
5	01/04/09	2030	09 00	60 56	1000
6	02/04/09	0730	08 00	61 27	1000
7	02/04/09	1600	07 00	61 51	1000
8	05/04/09	2000	06 00	62 42	1000
9	06/04/09	1400	05 00	63 07	1000
10	06/04/09	1030	04 00	63 34	1000
11	07/04/09	0630	03 00	64 00	1000
12	08/04/09	0630	02 00	64 21	1000
13	08/04/09	1300	01 0S	64 49	1000
14	08/04/09	2030	00 00	65 08	1000
15	09/04/09	0700	01 0N	65 35	1000
16	09/04/09	1600	02 00	66 01	1000
17	10/04/09	0000	03 00	66 29	1000
18	10/04/09	0800	04 00	66 57	1000
19	10/04/09	1700	05 00	67 24	1000
20	11/04/09	0700	06 00	67 58	1000
21	11/04/09	1430	07 00	68 19	1000
22	11/04/09	2230	07 50	68 42	1000

Table-13a

Sr.No.	Date	Time	Latitude (S)	Longitude (E)
1.	15/02/09	1800	30 00	57 30
2.	15/02/09	2345	31 00	57 30
3.	16/02/09	1000	32 00	57 30
4.	16/02/09	2355	33 00	57 30
5.	17/02/09	0715	34 00	57 30
6.	17/02/09	2200	35 00	57 30
7.	18/02/09	0600	36 00	57 30
8.	18/02/09	1730	37 00	57 30
9.	19/02/09	0010	38 00	57 30
10.	19/02/09	0700	39 00	57 30
11.	19/02/09	2000	40 00	57 30
12.	20/02/09	0700	41 00	57 30
13.	20/02/09	2000	42 00	57 30
14.	21/02/09	1130	43 00	57 30
15.	22/02/09	0400	44 00	57 30
16.	22/02/09	1145	45 00	57 30

17.	22/02/09	2130	46 00	57 30
18.	23/02/09	0600	47 00	57 30
19.	23/02/09	1700	48 00	57 30
20.	24/02/09	0130	49 00	57 30
21.	24/02/09	1130	50 00	57 30
22.	25/02/09	2200	51 00	57 30
23.	26/02/09	1030	52 00	57 30
24.	26/02/09	1845	53 00	57 30
25.	27/02/09	1030	54 00	57 30
26.	28/02/09	0100	55 00	57 30
27.	28/02/09	1030	56 00	57 30
28.	28/02/09	2230	57 00	57 30
29.	01/03/09	0230	58 00	57 30
30.	01/03/09	1030	59 00	57 30
31.	02/03/09	0730	60 00	57 30
32.	02/03/09	1515	61 00	57 30
33.	03/03/09	0245	62 00	57 30
34.	03/03/09	1030	63 00	57 30
35.	03/03/09	2030	64 00	57 30
36.	04/03/09	0800	65 00	57 30
37.	05/03/09	0800	66 00	57 30

Table-13b

Sr.No.	Date	Time	Latitude (S)	Longitude (E)
1.	08/03/09	1945	65 00	48 00
2.	09/03/09	0915	62 47	48 00
3.	09/03/09	1630	62 00	48 00
4.	10/03/09	0130	61 00	48 00
5.	10/03/09	0930	60 00	47 00
6.	10/03/09	1800	59 00	48 00
7.	11/03/09	0800	58 00	48 00
8.	11/03/09	2300	57 00	47 00
9.	12/03/09	1745	56 00	48 00
10.	13/03/09	0030	55 00	48 00
11.	13/03/09	1030	54 00	48 00
12.	13/03/09	1830	53 00	48 00
13.	14/03/09	0900	52 00	48 00
14.	14/03/09	1600	51 00	48 00
15.	15/03/09	0020	50 00	48 24
16.	15/03/09	1130	49 00	47 00
17.	15/03/09	1815	48 00	45 35
18.	16/03/09	1330	47 00	45 00
19.	16/03/09	2130	46 00	45 00
20.	17/03/09	0820	45 00	45 00
21.	17/03/09	1530	44 00	45 00
22.	17/03/09	2355	43 00	46 00
23.	18/03/09	1415	42 00	47 00
24.	20/03/09	1130	41 00	48 00
25.	20/03/09	1730	40 00	48 00
26.	21/03/09	0030	39 00	48 00
27.	21/03/09	1020	38 00	48 00
28.	21/03/09	1930	37 00	48 00
29.	22/03/09	0245	36 00	48 00

30.	22/03/09	1030	35 00	48 00
31.	22/03/09	1800	34 00	48 04
32.	23/03/09	0155	33 00	49 29
33.	23/03/09	1030	32 00	50 00
34.	23/03/09	1600	31 00	50 53
35.	23/03/09	2200	30 00	51 29
36.	24/03/09	0400	29 00	52 05
37.	24/03/09	1015	28 00	52 42
38.	24/03/09	1600	27 00	53 18
39.	24/03/09	2150	26 00	53 53
40.	25/03/09	0500	25 00	54 30

Table-13c

Sr. No.	Date	Time	Latitude (S)	Longitude (E)
1	31/03/09	0900	12 33	59 44
2	31/03/09	1300	12 00	59 54
3	01/04/09	1300	09 54	60 30
4	01/04/09	2030	09 00	60 56
5	02/04/09	0730	08 00	61 27
6	02/04/09	1600	07 00	61 51
7	05/04/09	2000	06 00	62 42
8	06/04/09	1400	05 00	63 07
9	06/04/09	1030	04 00	63 34
10	07/04/09	0630	03 00	64 00
11	08/04/09	0630	02 00	64 21
12	08/04/09	1300	01 0S	64 49
13	08/04/09	2030	00 00	65 08
14	09/04/09	0700	01 0N	65 35
15	09/04/09	1600	02 00	66 01
16	10/04/09	0000	03 00	66 29
17	10/04/09	0800	04 00	66 57
18	10/04/09	1700	05 00	67 24
19	11/04/09	0700	06 00	67 58
20	11/04/09	1430	07 00	68 19
21	11/04/09	2230	07 50	68 42

Table-14

Sr.No.	Date	Time	Latitude (S)	Longitude (E)
1	05/03/09	1205	66°10	57°31
2	05/03/09	1400	66°08	57°18
3	05/03/09	1645	65°54	57°02
4	06/03/09	1030	65°29	55°56
5	06/03/09	1215	65°44	55°45
6	06/03/09	1330	65°45	55°38
7	06/03/09	1715	65°33	54°53
8	07/03/09	0100	65°30	54°00
9	07/03/09	1030	65°32	53°00
10	07/03/09	1730	65°28	52°00
11	07/03/09	2200	65°28	51°00
12	08/03/09	0200	65°30	50°00

Table-15a

Sr. No	Date	Latitude (S)	Longitude (E)	Experiments Performed
1	17/02/09	35°00	57°30'	1 lt and 5 lt water collected for trace elements and Nd extraction respectively
2	19/02/09	41°00	57°30'	1 lt and 5 lt water collected for trace elements and Nd extraction respectively
3	25/02/09	51°00	57°30'	1 lt and 5 lt water collected for trace elements and Nd extraction respectively
4	05/03/09	64°00	57°30'	5 lt water collected for Nd extraction.
5	05/03/09	65°00	57°30'	1 lt water collected for trace elements.

Table-15b

Sr. No	Date	Latitude (S)	Longitude (E)	Experiments performed
1	13/03/09	55°00	48°00	1l water collected for trace elements.
2	15/03/09	49°00	47°00	1l water collected for trace elements.
3	17/03/09	44°00	48°00	1l water collected for trace elements.
4	20/03/09	41°00	48°00	1l water collected for trace elements.
5	21/03/09	38°00	48°00	1l water collected for trace elements.
6	22/03/09	35°00	48°00	1l water collected for trace elements.
7	25/03/09	32°00	48°00	1l water collected for trace elements.
8	25/03/09	25°47	54°02	1l water collected for trace elements.

Table-15c

Sr. No.	Date	Latitude (S)	Longitude (E)	Experiments performed
1	31/03/09	12 00	59 54	1l water collected for trace elements.
2	01/04/09	09 54	60 30	1l water collected for trace elements.
3	06/04/09	05 00	63 07	1l water collected for trace elements.
4	08/04/09	00 00	65 08	1l water collected for trace elements.
5	10/04/09	05 00	67 24	1l water collected for trace elements.

Table-16a

Sr.No.	Date	Time	Latitude (S)	Longitude (E)
1.	15/02/09	1800	30°00	57°30'
2.	15/02/09	2345	31°00	57°30'
3.	16/02/09	1000	32°00	57°30'

4.	16/02/09	2355	33°00	57°30'
5.	17/02/09	0715	34°00	57°30'
6.	17/02/09	2200	35°00	57°30'
7.	18/02/09	0600	36°00	57°30'
8.	18/02/09	1730	37°00	57°30'
9.	19/02/09	0010	38°00	57°30'
10.	19/02/09	0700	39°00	57°30'
11.	19/02/09	2000	40°00	57°30'
12.	20/02/09	0700	41°00	57°30'
13.	20/02/09	2000	42°00	57°30'
14.	21/02/09	1130	43°00	57°30'
15.	22/02/09	0400	44°00	57°30'
16.	22/02/09	1145	45°00	57°30'
17.	22/02/09	2130	46°00	57°30'
18.	23/02/09	0600	47°00	57°30'
19.	23/02/09	1700	48°00	57°30'
20.	24/02/09	0130	49°00	57°30'
21.	24/02/09	1130	50°00	57°30'
22.	25/02/09	2200	51°00	57°30'
23.	26/02/09	1030	52°00	57°30'
24.	26/02/09	1845	53°00	57°30'
25.	27/02/09	1030	54°00	57°30'
26.	28/02/09	0100	55°00	57°30'
27.	28/02/09	1030	56°00	57°30'
28.	28/02/09	2230	57°00	57°30'
29.	01/03/09	0230	58°00	57°30'
30.	01/03/09	1030	59°00	57°30'
31.	02/03/09	0730	60°00	57°30'
32.	02/03/09	1515	61°00	57°30'
33.	03/03/09	0245	62°00	57°30'
34.	03/03/09	1030	63°00	57°30'
35.	03/03/09	2030	64°00	57°30'
36.	04/03/09	0800	65°00	57°30'
37.	05/03/09	0800	66°00	57°30'

Table-16b

Sr.No.	Date	Time	Latitude (S)	Longitude (E)
1.	08/03/09	1945	65°00	48°00
2.	09/03/09	0915	62°47'	48°00
3.	09/03/09	1630	62°00	48°00
4.	10/03/09	0130	61°00	48°00
5.	10/03/09	0930	60°00	47°00
6.	10/03/09	1800	59°00	48°00
7.	11/03/09	0800	58°00	48°00
8.	11/03/09	2300	57°00	47°00
9.	12/03/09	1745	56°00	48°00
10.	13/03/09	0030	55°00	48°00
11.	13/03/09	1030	54°00	48°00
12.	13/03/09	1830	53°00	48°00
13.	14/03/09	0900	52°00	48°00
14.	14/03/09	1600	51°00	48°00
15.	15/03/09	0020	50°00	48°24
16.	15/03/09	1130	49°00	47°00

17.	15/03/09	1815	48°00	45°35
18.	16/03/09	1330	47°00	45°00
19.	16/03/09	2130	46°00	45°00
20.	17/03/09	0820	45°00	45°00
21.	17/03/09	1530	44°00	45°00
22.	17/03/09	2355	43°00	46°00
23.	18/03/09	1415	42°00	47°00
24.	20/03/09	1130	41°00	48°00
25.	20/03/09	1730	40°00	48°00
26.	21/03/09	0030	39°00	48°00
27.	21/03/09	1020	38°00	48°00
28.	21/03/09	1930	37°00	48°00
29.	22/03/09	0245	36°00	48°00
30.	22/03/09	1030	35°00	48°00
31.	22/03/09	1800	34°00	48°04
32.	23/03/09	0155	33°00	49°29
33.	23/03/09	1030	32°00	50°00
34.	23/03/09	1600	31°00	50°53
35.	23/03/09	2200	30°00	51°29
36.	24/03/09	0400	29°00	52°05
37.	24/03/09	1015	28°00	52°42
38.	24/03/09	1600	27°00	53°18
39.	24/03/09	2150	26°00	53°53
40.	25/03/09	0500	25°00	54°30

Table-16c

Sr. No.	Date	Time	Latitude (S)	Longitude (E)
1	31/03/09	0900	12 33	59 44
2	31/03/09	1300	12 00	59 54
3	01/04/09	1300	09 54	60 30
4	01/04/09	2030	09 00	60 56
5	02/04/09	0730	08 00	61 27
6	02/04/09	1600	07 00	61 51
7	05/04/09	2000	06 00	62 42
8	06/04/09	1400	05 00	63 07
9	06/04/09	1030	04 00	63 34
10	07/04/09	0630	03 00	64 00
11	08/04/09	0630	02 00	64 21
12	08/04/09	1300	01 0S	64 49
13	08/04/09	2030	00 00	65 08
14	09/04/09	0700	01 0N	65 35
15	09/04/09	1600	02 00	66 01
16	10/04/09	0000	03 00	66 29
17	10/04/09	0800	04 00	66 57
18	10/04/09	1700	05 00	67 24
19	11/04/09	0700	06 00	67 58
20	11/04/09	1430	07 00	68 19
21	11/04/09	2230	07 50	68 42

Table-17

Sr.No.	Date	Time	Latitude (S)	Longitude (E)
1	05/03/09	1205	66°10	57°31

2	05/03/09	1400	66°08	57°18
3	05/03/09	1645	65°54	57°02
4	06/03/09	1030	65°29	55°56
5	06/03/09	1215	65°44	55°45
6	06/03/09	1330	65°45	55°38
7	06/03/09	1715	65°33	54°53
8	07/03/09	0100	65°30	54°00
9	07/03/09	1030	65°32	53°00
10	07/03/09	1730	65°28	52°00
11	07/03/09	2200	65°28	51°00
12	08/03/09	0200	65°30	50°00

Table-18a

Sr. No.	Date	Latitude (S)	Longitude (E)
1	17/02/09	35°00	57°30'
2	19/02/09	41°00	57°30'
3	25/02/09	51°00	57°30'
4	05/03/09	64°00	57°30'
5	05/03/09	65°00	57°30'

Table-18b

Sr No	Date	Latitude (S)	Longitude (E)
1	13/03/09	55°00	48°00
2	15/03/09	48°00	47°00
3	17/03/09	44°00	48°00
4	20/03/09	41°00	48°00
5	21/03/09	38°00	48°00
6	22/03/09	35°00	48°00
7	25/03/09	25°47	54°02

Table-18c

Sr. No.	Date	Latitude (S)	Longitude (E)
1	01/04/09	09 54	60 30
2	02/04/09	08 00	61 27
3	05/04/09	06 00	62 42
4	06/04/09	04 00	63 34
5	08/04/09	02 00	64 21
6	08/04/09	00 00	65 08
7	09/04/09	02 00	66 01
8	10/04/09	04 00	66 57
9	11/04/09	06 00	67 58
10	11/04/09	07 50	68 42

Table-19a

Sr. No	Date	Latitude (S)	Longitude (E)	Experiments performed
1	17/02/09	34°30′	57°30′	New and Total productivity using C^{13}-N^{15} coupled tracer technique

2	19/02/09	38°00	57°30′	New and Total productivity using C^{13}-N^{15} coupled tracer technique
3	22/02/09	44°27′	57°30′	New and Total productivity using C^{13}-N^{15} coupled tracer technique
4	28/02/09	56°00	57°30′	New and Total productivity using C^{13}-N^{15} coupled tracer technique
5	04/03/09	65°00	57°30′	New and Total productivity using C^{13}-N^{15} coupled tracer technique
6	07/03/09	65°32′	53°06′	New and Total productivity using C^{13}-N^{15} coupled tracer technique

Table-19b

Sr.No.	Date	Latitude (S)	Longitude (E)	Experiments performed
1	13/03/09	54°	48°	New and Total productivity using C^{13}-N^{15} coupled tracer technique
2	16/03/09	47°	45°	New and Total productivity using C^{13}-N^{15} coupled tracer technique
3	20/03/09	41°	48°	New and Total productivity using C^{13}-N^{15} coupled tracer technique
4	21/03/09	38°	48°	New and Total productivity using C^{13}-N^{15} coupled tracer technique
5	22/03/09	35°	48°	New and Total productivity using C^{13}-N^{15} coupled tracer technique

Table-19c

Sr. No.	Date	Latitude (S)	Longitude (E)	Experiments performed
1	31/03/09	12 33	59 44	New and Total productivity using C^{13}-N^{15} coupled tracer technique
2	02/04/09	08 00	61 27	New and Total productivity using C^{13}-N^{15} coupled tracer technique
3	09/04/09	01 0N	65 35	New and Total productivity using C^{13}-N^{15} coupled tracer technique

Table-20a

St. No.	Date	Time	Depth (m)	Latitude (S)	Longitude (E)	Samples Collected				
						DO	PP(UF)	PP(F)	MZP	MeZP
1	16.2.09	1035	2428	31° 59'	57° 29'	S,10,20,30,50,80,100,120, 200,400,600,800&1000m	S,10,20,30,50,80,100,120,	s	S,10,20,30,50,80,100,120,	MPN, BONGO
2	17.2.09	1300	4500	35° 00'	57° 29'	S,10,20,30,50,80,100,120, 200,400,600,800&1000m	S,10,20,30,50,80,100,120,	s	S,10,20,30,50,80,100,120,	MPN, BONGO
3	18.2.09	1530	5300	36° 59'	57° 30'	S,10,20,30,50,80,100,120, 200,400,600,800&1000m	S,10,20,30,50,80,100,120,	s	S,10,20,30,50,80,100,120,	BONGO
4	19.2.09	920	5123	39° 01'	57° 29'	S,10,20,30,50,80,100,120, 200,400,600,800&1000m	S,10,20,30,50,80,100,120,	s	S,10,20,30,50,80,100,120,	MPN, BONGO
5	20.2.09	1030	4860	40° 59'	57° 37'	S,10,20,30,50,80,100,120, 200,400,600,800&1000m	S,10,20,30,50,80,100,120,	s	S,10,20,30,50,80,100,120,	MPN, BONGO
6	21.2.09	1200	4715	43° 01'	57° 31'	S,10,20,30,50,80,100,120, 200,400,600,800&1000m	S,10,20,30,50,80,100,120,	s	S,10,20,30,50,80,100,120,	
7	22.2.09	1230	4529	45° 03'	57° 32'	S,10,20,30,50,80,100,120, 200,400,600,800&1000m	S,10,20,30,50,80,100,120,	s	S,10,20,30,50,80,100,120,	
8	23.2.09	600	5700	47° 06'	57° 36'	S,10,20,30,50,80,100,120, 200,400,600,800&1000m	S,10,20,30,50,80,100,120,	s	S,10,20,30,50,80,100,120,	BONGO
9	25.2.09	1830		51° 00'	57° 32'	S,10,20,30,50,80,100,120, 200,400,600,800&1000m	S,10,20,30,50,80,100,120,	s	S,10,20,30,50,80,100,120,	
10	26.2.09	1600	4746	53° 00'	57° 30'	80,100,120, 200,400,600,800&1000m	80,100,120		80,100,120,	
11	27.2.09	1930		54° 00'	57° 30'	S				BONGO
12	28.2.09	100	4639	55° 00'	57° 30'	10,20,30,50,80,100,120, 200,400,600,800&1000m	10,20,30,50,80,100,120,		10,20,30,50,80,100,120,	
13	1.3.09	2330	5096	58° 59'	57° 05'	S,10,20,30,50,80,100,120, 200,400,600,800&1000m	S,10,20,30,50,80,100,120,	s	S,10,20,30,50,80,100,120,	
14	2.3.09	1530	4949	60° 59'	57° 30'	S,10,20,30,50,80,100,120, 200,400,600,800&1000m	S,10,20,30,50,80,100,120,	s	S,10,20,30,50,80,100,120,	BONGO
15	3.3.09	930	4723	62° 59'	57° 30'	S,10,20,30,50,80,100,120, 200,400,600,800&1000m	S,10,20,30,50,80,100,120,	s	S,10,20,30,50,80,100,120,	BONGO
16	4.3.09	700	3664	65° 03'	57° 27'	S,10,20,30,50,80,100,120, 200,400,600,800&1000m	S,10,20,30,50,80,100,120,	s	S,10,20,30,50,80,100,120,	BONGO
17	5.3.09	700	1820	65° 59'	57° 29'	10,20,30,50,80,100,120, 200,400,600,800&1000m	10,20,30,50,80,100,120,		10,20,30,50,80,100,120,	

Table-20b.

St. No.	Date	Time	Depth (m)	Latitude (S)	Longitude (E)	Samples Collected				
						DO	PP(UF)	PP(F)	MZP	MeZP
27	10.03.09	1700	5300	58° 59'	48° 01'	S &150m	S & 150		S & 150	
28	11.03.09	2300	4806	56° 59'	46° 52'	S	S		S	
29	13.03.09	1115	-	54° 00'	48° 01'	S				
30	13.03.09	1830	1401	53° 02'	48° 01'	S,50,80,100 & 150m	S,50,80,100 & 150m	s	S,50,80,100 & 150m	BONGO
31	14.03.09	1630	5501	50° 59'	47° 59'	S	S		S	
32	15.03.09	0900	5867	49° 00'	48° 1'	S,30,50,80 & 150m	S,30,50,80 & 150m		S,30,50,80 & 150m	
33	15.03.09	2008	5850	47° 59'	48° 03'	S				
34	16.03.09	1130	3266	47° 00'	45° 01'	S,30,50,80,100 & 150m	S,30,50,80,100 & 150m	S	S,30,50,80,100 & 150m	BONGO
35	16.03.09	2200		46° 00'	45° 00'					BONGO
36	17.03.09	0600	1423	45° 00'	45° 00'	S	S	S	S	BONGO
37	18.03.09	0200	3238	43° 00'	46° 59'	S,80,100 & 150m	S,80,100 & 150m	S	S,80,100 & 150m	BONGO
38	19.03.09	0045	3580	41° 00'	47° 59'	S,30,50,80,100 & 150m	S,30,50,80,100 & 150m	S	S,50,80,100 & 150m	BONGO
39	21.03.09	0001	2850	39° 12'	48° 00'	S,30,50,80,100 & 150m	S,30,50,80,100 & 150m	S	S,30,50,80 & 150m	BONGO
40	21.03.09	1630	3030	37° 00'	47° 59'	S,30,50,80,100 & 150m	S,30,50,80,100 & 150m	S	S,50,80,100 & 150m	BONGO
41	22.03.09	0825	3895	35° 00'	48° 00'	S,30,50,80,100 & 150m	S,30,50,80,100 & 150m	S	S,50,80,100 & 150m	BONGO
42	22.03.09	2345		33° 10'	49° 22'					BONGO
43	23.03.09	1030	4276	31° 53'	50° 19'	S,30,50,80,100 & 150m	S,30,50,80,100 & 150m	S	S,50,80,100 & 150m	BONGO
44	25.03.09	0025		25 47	54 02	-	-	-	-	BONGO

Table-20c.

St. No.	Date	Time	Depth (m)	Latitude (S)	Longitude (E)	Samples Collected				
						DO	PP(UF)	PP(F)	MZP	MeZP
1	31.3.09	1350	3555	12°00'	59°54'					BONGO
2	1.4.09	1300	1303	09°54'	60°30'	S,50,80,100 & 150m	S,50,80,100 & 150m	s	S,50,80,100 & 150m	BONGO
3	2.4.09	1050	3482	08°00'	61°27'					BONGO
4	5.4.09	2120	4114	06°00'	62°42'					BONGO
5	6.4.09	1400	4333	05°00'	63°07'	S,50,80,100 & 150m	S,50,80,100 & 150m	s	S,50,80,100 & 150m	-
6	6.4.09	1330	4399	04°00'	63°34'					BONGO
7	8.4.09	1300	3987	01°00'	64°49'					BONGO
8	8.4.09	2030	3776	00°00'	65°08'	S,50,80,100 & 150m	S,50,80,100 & 150m	s	S,50,80,100 & 150m	BONGO
9	9.4.09	1010	3538	01°00'	65°35'					BONGO
10	10.4.09	0950	3394	04°00'	66°57'					BONGO
11	10.4.09	1700	4053	05°00'	67°24'	S,50,80,100 & 150m	S,50,80,100 & 150m	s	S,50,80,100 & 150m	BONGO
12	11.4.09	1640	4390	07°00'	68°19'					BONGO
13	11.4.09	1420	4658	07°50'	68°42'					BONGO

Table-21.

St. No.	Date	Time	Depth (m)	Latitude (S)	Longitude (E)	Samples Collected	
						Mesozooplankton	Benthos
18	5.3.09	1145	394.7	66° 10'	57° 32'	BONGO	Grab
19	5.3.09	1500	203.5	66° 07'	57° 17'		Grab
20	5.3.09	1820	281	65° 54'	57° 02'	BONGO	Grab
21	6.3.09	1230	335	65° 44'	55° 44'		Grab(NS)
22	6.3.09	1325	300	65° 45'	55° 38'		Grab(NS)
23	6.3.09	1715	395	65° 33'	54° 53'		Grab(NS)
24	7.3.09	0.4	252	65° 29'	54° 00'	BONGO	Grab(NS)
25	7.3.09	945	356	65° 32'	53° 12'		Grab(NS)
26	7.3.09	1740	1450	65° 28'	52° 01'	BONGO	
27	1.4.09	1030	0029	10° 07'	60°27'		Grab

Table-22a.

Sl no	Date	Time	Latitude (S)	Longitude (E)
1.	16-02-09	17:45	32	57 30
2.	17-02-09	23:00	35	57 30
3.	18-02-09	18:30	37	57 30
4.	19-02-09	14:30	39	57 30
5.	20-02-09	14:00	41	57 30
6.	21-02-09	10:00	43	57 30
7.	22-02-09	Surface	45	57 30
8.	23-02-09	11:00	47	57 30
9	24-02-09	Surface	49	57 30
10.	25-02-09	Surface	51	57 30
11.	26-02-09	Surface	53	57 30
12.	27-02-09	19:30	54	57 30
13.	28-02-09	11:30	56	57 30
14.	01-03-09	10:00	59	57 30
15.	01-03-09	14:00	59	57 30
16.	02-03-09	19:45	61	57 30
17.	02-03-09	14:30	61	57 30
18.	03-03-09	14:15	63	57 30
19.	04-03-09	Surface	65	57 30
20.	05-03-09	14:00	66	57 30
21.	06-03-09	19:30	65	48 00
22.	07-03-09	01:15	65	48 00
23.	07-03-09	18:00	64	----
24.	08-03-09	04:00	63	48 00
25.	09-03-09	09:00	62	48 00
26.	10-03-09	10:00	60	47 00
27.	11-03-09	10:00	58	48 00
28.	12-03-09	18:00	56	48 00
29.	13-03-09	00:45	55	48 00
30.	13-03-09	10:00	54	48 00
31.	14-03-09	17:15	51	48 00
32.	15-03-09	00:00	50	48 24
33.	15-03-09	10:15	50	48 24
34.	16-03-09	15:15	47	45 00
35.	16-03-09	12;35	45	45 00
36.	17-03-09	08:00	43	46 00
37.	17-03-09	01:00	43	46 00
38.	18-03-09	09:00	42	47 00
39.	19-03-09	10:30	41	48 00
40.	20-03-09	11:30	41	48 00
41.	21-03-09	01:15	39	48 00
42.	21-03-09	07:30	37	48 00
43.	22-03-09	11:15	35	48 00
44.	23-03-09	01:00	33	49 29
45.	24-03-09	08:00	32	50 00

Table-22b.

St. No.	Date	Time	Latitude (S)	Longitude (E)
1	31.03.09	1350	12°00’	59°54’
2	01.04.09	1300	09°54’	60°30’
3	02.04.09	1050	08°00’	61°27’
4	05.04.09	2120	06°00’	62°42’
6	06.04.09	1330	04°00’	63°34’
7	08.04.09	1300	01°00’	64°49’
8	08.04.09	2030	00°00’	65°08’
9	09.04.09	1010	01°00’	65°35’
10	10.04.09	0950	04°00’	66°57’
11	10.04.09	1700	05°00’	67°24’
12	11.04.09	1640	07°00’	68°19’
13	11.04.09	1420	07°50’	68°42’

Table-23a.

St. No.	Date	Latitude (S)	Longitude (E)
1	16.02.09	32 00	57 30
2	31.03.09	35 00	57 30
3	01.04.09	39 59	57 30
4	02.04.09	40 59	57 30
5	05.04.09	43 01	57 30
6	06.04.09	55 00	57 30
7	08.04.09	59 00	57 00
8	08.04.09	65 03	57 30
9	05.03.09	66 00	57 30

Table-23b.

St. No.	Date	Latitude (S)	Longitude (E)
1	08.03.09	63 00	48 00
2	09.03.09	61 00	48 00
3	10.03.09	59 00	48 00
4	12.03.09	55 00	48 00
5	02.03.09	43 00	47 00
6	17.03.09	39 13	48 00
7	20.03.09	35 00	48 00

Table-24.

Sr. No.	Date	Latitude (S)	Longitude (E)	Sample collection	Time of collection
1	12/03/09	57°00	47°00	Water sample (25litres) (trial)	Light
	12/03/09	56°00	46°00	Water sample (25litres)	Bright

				(trial)	
2	13/03/09	53°54	46°00	Water sample (25litres)	Light
	13/03/09	53°00	47°59	Water sample (25litres)	Bright
3	14/03/09	51°25	48°00	Water sample (25litres)	Light
	14/03/09	51°00	48°00	Water sample (25litres)	Bright
4	15/03/09	49°00	48°00	Water sample (25litres)	Dark
	15/03/09	49°00	48°00	Water sample (25litres)	Light
5	16/03/09	47°00	48°00	Water sample (25litres)	Dark
	16/03/09	46°44	45°00	Water sample (25litres)	Light
6	17/03/09	45°00	46°00	Water sample (25litres)	Dark
	17/03/09	44°00	46°00	Water sample (25litres)	Light
7	18/03/09	43°24	48°00	Water sample (25litres)	Dark
	18/03/09	43°00	48°00	Water sample (25litres)	Light
8	19/03/09	41°00	48°00	Water sample (25litres)	Light
	20/03/09	41°00	48°00	Water sample (25litres)	Dark
9	21/03/09	38°12	48°00	Water sample (25litres)	Dark
	21/03/09	37°13	48°00	Water sample (25litres)	Light
10	22/03/09	35°00	48°00	Water sample (25litres)	Dark
	22/03/09	34°34	48°19	Water sample (25litres)	Light
11	23/03/09	31°53	32°18	Water sample (25litres)	Dark
	23/03/09	30°00	49°18	Water sample (25litres)	Light
12	24/03/09	28°00	52°00	Water sample (25litres)	Dark
	24/03/09	28°29	52°29	Water sample (25litres)	Light

Table-25.

Sta. No	Date	Time	Latitude	Longitude	Core length	Depth (m)	Remarks
1	20/02/09	2230	42°00.00'S	57°30.00'E	-	4726	Sediment not retrieved
2	23/02/09	1700	43°00.00'S	57°30.00'E	-	4720	Sediment core not retrieved; But very hard clay silt (very little) collected in the core catcher
3	01/03/09	1100	59°00.00'S	57°30.00'E	-	5100	Core failure
4	04/04/09	1130	07°29.54'S	62°05.37'E	-	3875	Sediment not retrieved
5	05/04/09	2330	06°12.29'S	62°05.00'E	4.5 m	4114	Entire core Calcium carbonate, White
6	07/04/09	1405	02°30.00'S	64°15.00'E	4.0 m	4710	Entire Calcium carbonate, white
7	12/04/09	0800	09°29.45'N	68°38.83'E	4.0 m	4594	Top dark yellow, bottom light yellow

Table-26.

Grab operations					
Sr. No.	Date	Time	Latitude (S)	Longitude (E)	Depth (m)
1	05/03/09	1320	66 09.5	57 30.4	407

2	05/03/09	1510	66 08.1	57 18.5	202
3	05/03/09	1845	65 54.6	57 01.4	280
4	06/03/09	1223	65 44.2	55 44.9	336
5	06/03/09	1325	65 45.8	55 37.9	206
6	06/03/09	1715	65 33.0	54 53.0	395
7	07/03/09	0040	65 29.2	54 00.0	252
8	07/03/09	0945	65 32.6	53 12.4	356
9	01/03/09	1030	10 07.0	60 27.0	029

Table-27.

Sl no	Date	Time (IST)	Latitude	Location	Visibility	Light Description
1.	160209	12:00	Between 32°S & 35°S	West	Clear sky	Bright yellow-lemon sized-moving-disappears after 10secs
2.	170209	13:00	42°S	West	Clear sky	White light-travelling dot sized- gradually expanding about 2inches above ship-retracts to a dot-disappears. time taken, 7 secs
3.	160309	00:00	45°S	East	Cloudy in patches	Yellow light -1&1/2 inches-props out in the west for 3 secs. disappears
4.	210309	00:10	39°S	South	Cloudy in north west	Sparkling White light-2inches-props out in the south for 3 secs.
5.	250309	12:20	Between 30°S & 25°S	West	Clouds in patches	Moving like satellite-expands abt 2inches in the west. appears to be stationary for3 secs. disappears.
6.	260309	19:15	21°S	East	Clear sky	White light-resembling a bright star as Sirius-remains stationary for 4 secs. Gradually moves eastward-shrinks and disappears.